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MENTAL LOADING OF PROCESS OPERATORS: AN ATTEMPT TO DEVISE A METHOD OF ANALYSIS AND ASSESSMENT

By J. B. Kitchin and A. Graham*

The paper describes some work done by Imperial Chemical Industries as part of a study of the non-physical contribution of process operators. A tentative procedure was developed which had as its basis a detailed study of job requirements and a method of classifying types of mental load. A points scoring system was devised in order to attempt to quantify these classes of mental load. As the experiment progressed, the 'technique' developed into a systematic method of analysing decision-taking situations and an arbitrary procedure for comparing these situations quantitatively. The approach was essentially of the 'works-experimental' type. The main results of the experiment were the clarification of ideas on non-physical contribution and some indications for future work.

§ 1. Introduction

Much attention has been paid in recent years to the problems associated with the current industrial trend towards production methods which make demands on the operator of a mental, rather than a physical, nature. However, laboratory studies on matters such as perception, vigilance and mental fatigue, have of necessity been conducted on narrow fronts. Since the scope of the whole problem is very great, the results of separate laboratory studies have not yet been integrated to provide industry with generally applicable and workable techniques which can be used in plant design and in the control of operator effectiveness. Further, much of the research work has been concerned with operators working under extreme conditions of load. While extreme loads (mental or physical) certainly exist in industry, they no longer exist to the extent which might be inferred from the emphasis given to them by research workers.

The industrial problem differs from the normal laboratory problem in three major respects:

(1) The mental load on the industrial operator is often the integrated effect of a complex set of independent or inter-acting factors, whereas the mental load on the laboratory subject is usually the effect of a small number of closely-controlled factors.

(2) In industry, the operator's task lasts for 8 or 9 hours a day, five days a week, whereas the laboratory subject is loaded for relatively short periods.

(3) Peak loads in industry occur relatively infrequently and are of short duration, but in the laboratory peak loads are artificially produced over relatively long periods.

The work summarized in this paper was an attempt by Imperial Chemical Industries Limited to see if it were possible to develop a practical technique for assessing the mental load on process operators, against a background of the limited relevance of laboratory findings to complete industrial jobs.

* J. B. Kitchin is Personnel Director of the Plastics Division of I.C.I. Ltd. At the time when the work reported here was carried out, he was Deputy Head of the Central Work Study Department of I.C.I. Ltd. in which department A. Graham is currently Head of Pre-Production Section.

Since the ' laboratory ' for these trials was the manufacturing plants of the Company, the test conditions were of necessity much less closely controlled than the conditions of a properly conducted scientific experiment. Also, because of the lack of time and research facilities, a certain amount of subjective judgment was a necessary feature of the exercise. It should be emphasized at the outset, therefore, that these trials were not in any sense scientific experiments, but an attempt to develop an empirical system for practical use. Nevertheless, the authors believe that the ' works experimental ' approach and the findings of the trials should be of interest to people on both sides of the gulf which sometimes appears to separate the biological research worker from the industrial manager.

§ 2. Objectives of the Trials

For many years and for many purposes I.C.I. has made considerable use of the techniques of work study. As part of this activity, work measurement techniques have been used widely to assist management decisions on several types of problem, including plant manning and the devising of direct financial incentive schemes. In these two fields the work measurement techniques are eminently satisfactory provided that the work done by the operator is predominantly physical in nature. They have only a very limited usefulness, however, in studying activities which are predominantly non-physical.

In view of the trend towards more complex and highly-instrumented plants, it was felt that an attempt should be made to devise some parallel technique which would provide information on that part of the process operator's contribution which cannot be expressed by work measurement. Such a technique would, it was believed, be of value in several types of industrial problem wherein it is important to know an operator's total contribution to the achievement of objectives specified by management.

The trials were initiated, therefore, with the intention of trying to develop a procedure for assessing, to an acceptable degree of consistency, the mental activities involved in some typical jobs in the Company. It was regarded as essential that the technique of assessment should be of practical value to management; a crude but workable tool was preferable to an ' accurate ' but unwieldy one. Further, the technique had to take into account the established value of work measurement techniques in the area of physical work, and had to provide a sensible complement thereto.

The authors stress the importance of these practical considerations. It was not regarded as appropriate to try and measure mental work, in the sense of expenditure of ' mental energy '. Such an approach was best left to the research workers outside industry. Whether, indeed, such an approach is possible, is outside the authors' competence to say. However, in the present state of knowledge, it would in their opinion be exceedingly difficult to develop such an objective measurement technique which could be used economically in industry, bearing in mind the extent to which individual human characteristics and abilities influence the amount of 'mental energy' which the particular individual must expend in carrying out a specific mental activity.

§ 3. The Scope of Work Measurement

In attempting to analyse the non-physical component of an operator's contribution, it became necessary to define carefully the extent to which conventional work measurement techniques could properly be used, in order to avoid any overlap. Clearly no work is purely physical, since mental work of some sort is an integral part of every purposeful human activity.

As a result of much study, it was shown that work measurement techniques, applied intensively, could give a satisfactory quantitative expression of three types of mental activity on a time basis:

(1) Mental activity involved in directing and co-ordinating muscular activity, i.e. during all defined physical movements of the body, including highly manipulative work.

(2) Mental activity in perception (taken to mean the actual receipt of information by any of the senses).

(3) Mental activity of the senses in searching for a random stimulus; in particular, alertness to pick up a random (but likely) signal demanding instant action.

Summarizing, work measurement, although predominantly a technique for measuring work which can be observed as being carried out physically, satisfactorily recognizes for practical purposes those mental activities which are an integral part of some physical activity and which are defined by the physical activity which they accompany in time.

§ 4. A Basis for Assessment

It was desired to determine what other active contribution, if any, an operator made, which could not be determined quantitatively by work measurement. In view of the success achieved in the use of work measurement to determine the physical work of the operator, the possibility of using an analogous technique to assess the effort not covered by work measurement was considered. Work measurement expresses physical effort on a time and intensity basis and expresses the work content of the task in terms of the time the task will take to perform at a specified level of performance. The intensity of effort is recognized in two ways. Firstly. the operator's rate of working is rated against an accepted standard. Secondly, an allowance is made for time to recover from the effects of fatigue. This recognition of intensity of physical effort is based on the conception of the average operator, suitably skilled and trained for his task, and on judgment, based on experience, as to what proportion of an operator's physical capabilities it is reasonable to expect him to expend during the average working period. Although these concepts are, of course, empirical in origin and practice, a great deal of industrial experience has shown that this time-and-intensity approach is satisfactory for physical work measurement.

However, when consideration was given to the purely mental activities carried out by the industrial operator, it was evident that there was little data about the types of such activity, and even less about times necessary to perform them. Such evidence as there was, suggested that these times were extremely small and difficult to isolate. Furthermore, the intensity of mental effort caused by a particular demand depended on the abilities and skills of the

operators concerned and probably also upon the type of mental activity called for, to a much greater extent than in the case of physical activities. It was thought that, as so little was known about the mental capacities of operators, the assessment of intensity of mental effort could only be a subjective judgment of doubtful validity.*

It was therefore decided to reject the time-and-intensity approach to mental effort, and try instead to develop a method of assessment which did not have a short-term time base.

The approach which appeared to hold out the greatest chance of sound development, was one which considered the type and complexity of the mental activity on each occasion when it was *demanded by the job*, if it were to be done at a particular level of efficiency specified by management. By combining the assessment of complexity of each mental activity with a measure of the number of occasions upon which it was exercised during a broad time period, it was thought that an assessment of the mental load imposed by the job might be made. Thus the concept of ' mental effort ' was replaced by one of ' mental load '. The mental load was concerned with the demands made by the job, and did not attempt to take into account the ability of operators to deal with such demands. It did, however, involve consideration of the ways in which operators reacted to, and thought about, their jobs.

§ 5. Types of Mental Activity

In the range of general worker jobs with which the investigation was concerned, it was thought that there would be a number of differing mental activities which formed part of the operator's total contribution after the physical and associated mental activities properly assessable by work measurement had been recognized. It was decided that any attempt to assess the mental load imposed by such activities should be based on a detailed analysis of the task rather than on any attempt at overall measurement or assessment. Such an analysis, to be of value, had to be able to differentiate between various kinds of mental activity.

At the beginning of the trials, but after consideration of a number of tasks carried out by a range of operators, it was thought that the following classes of activity might be found to impose, to a greater or less degree, a mental load on general workers in a process industry:

(1) Control operations.
(2) The recognition of an achieved state.
(3) Monitoring.
(4) Inspection.
(5) Memory.

* The authors believe that these observations about lack of knowledge in this field are fair comment, judged in the context of I.C.I.'s investigation. However it should not be inferred that the authors did not recognize the importance, in other fields of application, of the pure and applied research into mental activities being done by many other people. Indeed, the initial thinking of the I.C.I. investigators was influenced by discussions with several of these research workers. The authors wish to record their appreciation of the encouragement given, in the early days of the investigation, by Dr. E. R. F. W. Crossman of Reading University and Dr. N. H. Mackworth and his then colleagues at the Medical Research Council's Applied Psychology Research Unit.

(6) Planning.
(7) Mental arithmetic.
(8) Alertness or Vigilance.

In order to use these classes as the basis for the detailed analysis of tasks in the field it was necessary to define them with reasonable precision.

Control Operations

This class covered the control of certain continuous variables or situations, in which the operator was required to examine and judge fluctuations within and outside the acceptable limits and decide on the corrective action to be taken, if any. The action took the form of adjustment to operating conditions, the sense and magnitude being determined by the operator. An example would be controlling steam pressure from a boiler plant under conditions of varying steam demand by adjusting the output of one boiler.

Recognition of an achieved state

This class was restricted to the operations where the progression of a variable or the development of a situation was (*a*) independent of the operator and (*b*) unidirectional, and where it was known to the operator that a predetermined condition would be arrived at which then left him with only a single predetermined course of action. This would occur, for example, in an exothermic chemical reaction, if the operator is required to take a specific action once a particular temperature has been reached.

Monitoring

This class dealt with the case where a variable was allowed to move within specified limits, and where action defined in nature and extent had to be taken if the limits were exceeded. The class was restricted to the monitoring of variables which were independent of the operator, and took into account the importance of anticipation by studying trends. This differed from the previous class in that the direction of movement of the variable was itself variable and there was no inevitability about the ultimate end point it would reach. For example, an operator on an instrumented plant might be required to watch the trend of the air pressure which actuates his instruments. If an undesirable trend develops he can take no direct corrective action, but can only report the matter to some other authority.

Inspection

This class contained inspection operations in which judgment between acceptance or rejection was required because the distinction between acceptance and rejection standards was not precisely defined. This might occur in the inspection of a product for colour, where fine distinction between shades is necessary.

Memory

This class covered the short-term memorizing of items of current information about a situation or process. It took into account the various items of information which an operator had to pick up at the beginning of each spell of work and retain in his memory during that spell. For example, he might have to remember what material was being processed in a particular batch reactor, and its state and progress. Or he might have to remember the number of compressors available for a particular duty during the shift.

Planning

This class was concerned with operations where an operator had to plan his work ahead so that a number of tasks could be fitted together into a programme, or where action had to be taken when a predicted state of affairs was reached. Examples would be planning the sequence of operations on a multiproduct batch process plant, and planning the optimum utilisation of railway wagons of different types for despatching orders of varying sizes.

Mental Arithmetic

During the preliminary considerations it was thought necessary to introduce a means of dealing with operations involving simple arithmetical calculations, and a tentative procedure was devised. This class was later deleted, because after close study it was felt that such arithmetic as was done by process operators was below the threshold of mental activities which the experiment sought to assess.

Alertness

It was initially considered that one type of mental activity had to be assessed on a time base. This activity was termed Alertness, and the term Vigilance might equally well have been chosen. Alertness was said to exist in operations in which the state of a process or situation was liable to change rapidly in a manner which required decisive and predetermined action to be taken promptly. The operator had to be in a state of readiness to detect critical stimuli, the occurrence of which was known to be likely but which could not be predicted accurately in time.

Towards the end of the experiment it was decided that, although Alertness in this sense did exist in some of the jobs studied, it could be adequately and appropriately recognized by conventional work measurement techniques, because the Alertness was almost always an integral part of some physical activity. This class was therefore deleted, and instead there was included the third type of mental activity already reported in § 3 as being within the scope of work measurement.

Having defined, at any rate in a preliminary manner, the various classes of mental activity which one might expect to find in the range of tasks under consideration, it became necessary to devise field trials to determine the practicability of (*a*) recognizing the occurrence of these classes of mental activity and (*b*) setting up a system of quantitative assessment of such activities.

§ 6. Organization of Experimental Trials

The preliminary work detailed above had been carried out by a small directing group consisting of experienced representatives of line management and specialists in labour management and work study. The authors were members of this group, which also guided the field trials. These were carried out by a number of similarly constituted teams consisting of 5–8 members operating in several of the Company's manufacturing Divisions. In all, about 40 senior people were engaged full-time on the experiment for about four months. A range of jobs was selected in each Division and each team was briefed in detail as to the analytical methods to be used in examining the various jobs.

Between 50 and 60 complete jobs were studied, ranging from those demanding a high degree of skill and responsibility to those involving little or none. Thus the investigation covered a cross-section of all types of general worker jobs done in the Company, and was not restricted to those wherein the worker's non-physical contribution was clearly significant. Where it was possible, similar jobs were selected on two or more manufacturing sites in order to provide a cross check as to the validity of the techniques when used by independent teams.

Each of the operating teams examined in considerable detail the selected jobs in its own Division, calling into consultation as necessary the line management, supervision, and workers concerned. Much use was made of existing information derived from earlier work study and job evaulation investigations. From time to time during the course of the field trials discussions were held with the directing group to ensure that each field team was proceeding consistently. As might be expected, it was found as the investigation progressed that the original definitions and ideas required some modification in the light of experience. Any such modifications were agreed by the directing group before being adopted by the field teams. The descriptions of mental activities given in § 5 are based on the definitions which were finally agreed upon.

§ 7. Initial System of Scoring

The method of analysis so far described was, of course, only qualitative, whereas it was desired to find some quantitative expression of mental load. Since the approach was quite different from that of work measurement, or that used by any other investigators known to the I.C.I. team, it was clearly necessary to devise an original method of quantification. A quite arbitrary and tentative procedure of points scoring was decided upon, and different classes of mental load were treated in different ways, as follows:

Control Operations. Points were awarded on a ‘ per occasion ’ basis according to (*a*) the number of items of information which had to be taken into account by the operator, and (*b*) the number of possible courses of action open to him in making his decision about the action to be taken (or not to be taken). For the first attempt it was decided to give one point for each item of information which required to be taken into account in the analysis of the situation, and one point for each possible course of action open to him. The two sets of markings were then added together to give a points score per occasion.

Whether the linear and additive treatment was justified appeared doubtful at the outset, but the possibility of using non-linear scales was left open for future development.

Recognition of an achieved state. One point was awarded for each factor concerned in the definition of the state to be achieved. One point was added if there was a specially urgent relationship in time between the recognition of the achieved state and the action to be taken.

Monitoring Operations. One point was awarded each time the variable was examined.

Inspection Operations. One point was awarded each time an inspection resulted in the rejection of the item inspected. An additional point per occasion

was awarded if the judgment was concerned with a balance between two or more factors. It was realized that this treatment excluded any credit for judgment followed by acceptance of the item. In the general case, however, it was felt that this was counterbalanced by the unwarranted credit given for rejects which had been so obviously outside specification as to demand no real judgment.

Memory. This was tentatively scored at a flat rate of ten points per item per working shift.

Planning. The scoring method was the same as that for Control Operations.

Alertness. Assessment of this class of mental activity was quite subjective. The experimenters related the Alertness in each task to a 5-step linear scale related to the amount of Alertness judged to exist in driving a commercial road vehicle in certain specified conditions. This gave the ‘ Degree of Alertness ’, which was multiplied by the minutes of duration to give a points score. This was exceptional in that it had a time base. As has already been noted, this class was eventually deleted.

Since the points scale under each class of mental activity was quite arbitrary, it was realized at the outset that if the described method of assessment were to be followed to a useful conclusion, it would ultimately be necessary to arrive at weighting factors for each class. Thus a total weighted score per shift, covering all mental activity not recognized by work measurement, could be calculated for each job. For reasons which will become evident, these weighting factors were never in fact finalized.

7.1. *Load over Working Period*

With the exception of the *Memory* class, the points scoring scales were on a ‘ per occasion ’ basis: that is, the score indicated the relative mental load imposed by that activity when done once only. Although time measurement was not involved in deriving any of these scores, it became necessary to reduce them to a common time base to allow comparisons between jobs. It was decided to adopt the normal working period of a day or shift as the common time base; scores ‘ per occasion ’ had, therefore, to be adjusted according to the frequency of the particular activity, so as to give a score which represented that activity's contribution towards the total mental load imposed by the job over a whole day or shift.

Initially, frequency of occurrence was taken to have a straight multiplying effect on the mental load per occasion. That is, if a particular *Control Operation* scored five points per occasion, and occurred 12 times per shift, then the *Control Operation* load for this particular task in the job was represented by 60 points. Apart from the doubtful validity of the original assumption, which is discussed later, the problem arose as to the interpretation of frequency of occurrence. An instrument might have been examined 16 times per shift, yet only four occasions called for real judgment and only two called for remedial action. Thus the total mental load per shift imposed by this instrument could have three expressions, depending on whether the frequency was based on examination, judgment or action. It was felt that the judgment frequency was the most important, and the most appropriate in the context of the investigation, but was very difficult to determine. Action frequency, readily determinable, was accepted as the most practical basis for assessment.

§ 8. Interim Results of the Experiment

The results took two forms. Firstly, for each of 50 whole jobs in the Company, there were figures purporting to represent the mental load per shift resulting from several types of mental activity. Secondly, a tremendous amount of new information about jobs, and understanding of the mental processes involved therein, had been acquired by a large number of experienced managers, engineers, labour officers, and work study officers.

It was a formidable task to collate the arithmetical results and to interpret them in the light of the often divergent views of the investigators. Each of the operational teams spent two days discussing with the directing group their own teams' results, their interpretation of these results, and their views on the technique of assessment. During this period of recapitulation, the main questions to be answered were as follows: Did the method of analysis and the scoring procedure (assuming proper weighting of points in different classes could be agreed) provide a consistent, valid, and workable technique (or the beginnings of one) for assessing mental load in process jobs? If not, why not? Experimental teams were by no means unanimous in their replies to these questions, and individual views of some aspects of the technique ranged from cautious acceptance to forthright rejection. A good deal of constructive criticism was made, however, which enabled the directing group to revise its approach.

Consistency

Inadequate definition of classes of mental activity proved to be an obstacle to the attainment of consistency. Although considerable attention was paid by all teams to problems of definition, inconsistency arose between teams—and even between jobs studied by the same team—because of the practical impossibility of defining the classifications well enough for them to be comprehensive yet unambiguous. Difficulties also arose from inability to specify clearly at the outset the threshold level of mental activity below which an activity was decreed to be insignificant and therefore outside the scope of the technique.

Validity

Validity was difficult to deal with. Normal procedure for validating the results of scientific experiment could clearly not be used. There were in fact no absolute criteria by which the results could be judged. The best that could have been hoped for was that the total weighted scores inter-related the jobs in a way which seemed to make sense to the experimental teams; that is, that the technique gave an inter-relation which lined up reasonably well with one arrived at by making an overall, subjective, but informed and sophisticated judgment about the relative amounts of mental load in these jobs. In acknowledging the limitations of such a means of validation, the authors would stress that in the confusing complex of uncontrollable factors which affect human problems in the real industrial situation, such a subjective approach is often not merely the *only* procedure, but a quite satisfactory one.

In the event, the procedural defects of the experimental method made it inappropriate to attempt such a validation. It was more appropriate, and more profitable, to consider validation much more qualitatively, by discussing the experimenters' theoretical views on the nature of the mental work being

assessed, and on their practical experiences of the embryo technique. Considerable divergence of opinion was found, as was perhaps to be expected. Some teams felt that the technique could be readily improved and adopted to give a valid means of expressing the kind of mental load they sought to recognize. Others disagreed, for a number of reasons. The main criticism was directed at the arbitrary system of points scoring, which did not make sufficient distinction between mental activities of varying complexity. Further, it was felt that the threshold had been set too low, and that the mental load attributed to many simple activities had been unrealistically high. Again, the straight multiplier approach to the frequency effect gave a distorted picture of mental load.

Several teams expressed the opinion that there was another type of mental load which existed in some jobs—notably in the control of highly-instrumented plants—which the technique did not recognize. This was the background mental load continuously imposed on an operator by virtue of his having to bear in mind the state and significance of a number of concurrent variables relevant to the process being controlled.

Workability

When workability of the technique was considered, a greater degree of unanimity was apparent. The technique was extremely complicated and difficult to apply. Certainly a great deal of information had been thrown up which would be valuable in other respects; but, considering the technique merely as an assessment procedure, most people thought it was cumbersome and quite uneconomic as a practical tool in industry. It was generally felt that a simplified approach could and should be developed.

§ 9. Simplified Technique

The directing group set themselves the task of developing an improved and simplified technique which took into account the constructive criticisms which had been made, and which was based on a new and clearer understanding of the nature of the problem and its possible solution. After much theoretical consideration, and a further limited amount of experiment, it was concluded by the central team that mental load could be satisfactorily expressed in two parts. These were the decision-taking load and the background mental load.

Decision-taking load

Considering the classes of mental activity in use at the end of the experiment it was evident that, with the exception of Memory, they all had a common element of decision-taking. The central idea of decision-taking was therefore chosen as a basis for a one-class assessment technique.

A decision-taking situation was said to exist when an operator's course of action was determined by consideration of the current factors in the situation. That is, when there had been no precise specification as to

WHAT had to be done
HOW MUCH had to be done, and
WHEN it had to be done

Thus a decision was involved if the operator had any discretion in the nature, extent, and timing of an action. It was accepted that a decision taken by a particular operator might call for pure reasoning, the application of memory

patterns, or any combination of the two. Looked at in terms of the job, however, the nature of the operator's mental effort was not of real importance. For this reason, and because in fact it would have been impossible to establish the ratio of reasoning to memory in each situation, it was concluded that decisions should be analysed on the assumption that only reasoning was involved.

Decisions were analysed under five headings, and another arbitrary (but, it was thought, more realistic) points scoring method was devised, as follows:

(*a*) *The number of factors in the situation.*. The score was obtained by subtracting one from the number of factors (items of information) relevant to the decision. The subtraction eliminated many simple situations wherein no real judgment was necessary in order to reach a conclusion regarding the course of action.

(*b*) *Complexity of comprehension of each factor.* Points from 0 to 4 were awarded by subjectively comparing each factor with a set of fixes. For example, no points were awarded for simple factors such as instrument readings and observation of simple physical facts and conditions such as a level in a sight glass. Four points were awarded for a factor which could be comprehended only by making an overall assessment of many interacting elements which constituted the factor, such as the state of a boiler fire-bed.

(*c*) *Memory.* One point was awarded for each factor brought to the decision-taking situation from the short-term memory.

(*d*) *Interdependency of factors.* One point was awarded for each pair of factors in the decision which were interdependent insofar as the desired value of one factor was dependent on the actual value of the other.

(*e*) *Delay characteristics of situation.* The mental load in a decision was increased if there was in the process an inherent delay in the feedback of the effects of any action the operator might take. One point was awarded if the delay was greater than one minute, and an additional point if the system had non-averaging characteristics.

For each decision, a points score per occasion was obtained by adding up the points awarded to that decision under each of the five headings above.

The original approach had been criticised because of its complication, and the revised one-class procedure went a long way towards meeting this criticism. The earlier feeling that the datum had been set too low, was met by the simple device of deducting one from the score attributable to the number of factors. This eliminated a great many very simple 'decisions', indeed almost all single-factor 'decisions' where the factor was in itself simple to comprehend. Further, the inclusion of a scale of comparative fixes for complexity was an attempt to remedy a criticised defect in the original treatment.

The last major criticism had been concerned with the effect of frequency.

Effect of frequency

It was decided to continue to base the assessment of mental load arising from a decision-taking situation on the number of times this situation led to positive action in the average shift.

The straight multiplying effect of frequency used in the experiment, however, was thought to be unrealistic. If a particular decision merited x points for one occurrence, and resulted in action 10 times per shift, then the total

load per shift was not necessarily represented by $10x$. Repetition naturally meant greater familiarity with the situation, so that each repetition of a decision in a particular situation incurred a smaller amount of reasoning than before. The situation tended, in the extreme, to demand little more than automatic or reflex action. It was not possible, or indeed appropriate, to be very theoretical about devising a new scale of frequency multipliers. Rather, a scale was sought which not only looked reasonably sensible but gave sensible results when applied to the ' per occasion ' scores. The following table of multipliers was ultimately drawn up.

Frequency of the particular decision	*Multiplier*
Not less frequently than once per 20 working periods, but less than once per working period	1
Once or twice per working period - -	2
3 to 8 times per working period - -	3
9 to 32 times per working period - -	4
33 or more times per working period -	5

This scale was very much ' flatter ' than the original one. Although much more experimental work was thought to be necessary, it was felt that any departure from this new scale should be in the direction of even more ' flatness '. In the extreme, it was thought possible that all multipliers might be unity. That is, that the effect of frequency might be ignored altogether, the total shift load of a decision being represented by the points score per occasion.

§ 10. Subjective Validation

The revised one-class assessment was applied to 43 of the original jobs. Because the results of the original experiment on a 6–class basis had been fully documented, it was possible to apply the revised procedure without further field trials. After a certain amount of necessary consultation with the Division teams, the directing group were able to re-classify and re-score the mental activities originally recorded, as an office exercise.

It was possible, therefore, to produce for each job a number of points which represented the total decision-taking load in that job, being the sum of shift scores for each decision in the job. Each Division team had made a subjective judgment of the relative amounts of mental load in the jobs they had examined, without regard to any points scores derived during the first part of the experiment, and this was used as a yardstick by which to make a rough test of the validity of the analytical technique. The result of this test was reasonably satisfactory. By and large, the analytical technique ranked the jobs in the same order as the subjective judgment of the highly-experienced experimenters. There were some notable exceptions, but there were usually special features in these jobs which explained the discrepancy.

However, although the order of ranking was fairly satisfactory, the absolute values of the decision-taking loads were of unknown validity. In other words, the technique had placed the jobs fairly sensibly on the rungs of a decision-taking ladder, but little was known about the correctness of the spacing between the rungs, or about the length of the ladder and its position relative to the ground.

Background mental load

The above validation was done without considering the background mental load which was believed to exist in some jobs. This omission was made deliberately for two reasons. (1) The concept of a background load was formulated too late in the experiment to allow any development. (2) It was believed that, in terms of the relative effect on the operator, background mental load was much less significant than decision-taking load. Therefore, for this experiment, decision-taking load was regarded as a satisfactory expression of total mental load. Background mental load offered a useful field for further experiment, and it was tentatively proposed that this load might be roughly expressed by merely counting the number of concurrent sources of information in the process.

§ 11. Conclusion

(1) The method of analysing decision-taking situations showed promise as a step towards the development of a largely objective and practical means of ranking process jobs in terms of the mental load imposed on the operators. The step was perhaps a faltering one, but it was undoubtedly in the right direction.

(2) There was scope for further research on the problems of decision-complexity, frequency effect, and background mental load. However, the tentative decisions on these matters, made during the trials, seemed to be reasonably acceptable in the context of the immediate uses to which the results of the technique were likely to be put.

(3) The technique was complementary to the techniques of work measurement, inasmuch as it gave information on a part of the operator's contribution not expressed by work measurement. It was not complementary to work measurement in the sense of giving an expression of mental effort based on time and intensity which could be added directly to the time necessary for the physical work at a specified level of performance. However, in the authors' view, mental effort expressed as a rate of working is at this time a concept of little practical value in their industry.

(4) Many indirect benefits resulted from the trials, principally connected with the increased understanding of process-controlled situations which was gained by management. The authors believe that the knowledge which can be derived from such an analysis of mental loading can be of value to management in the following areas:

- (i) Plant design; in particular the design and layout of instruments and controls.
- (ii) The study of existing process operating methods with a view to improvement.
- (iii) Operator specification and selection.
- (iv) The drawing up of plant operating instructions.
- (v) Operator training.
- (vi) The planning of operator deployment in advance of plant construction.

§ 12. Some Final Observations

In these days of advanced techniques of manufacture, complex processes, automation and so on, many industries are facing problems concerned with the balance of physical and mental abilities demanded of their operators. It is frequently said that a new breed of industrial operator is becoming necessary, an operator of higher intelligence and with a greater understanding of modern technology. This is a very big subject, and outside the scope of the present paper. In comment, the authors would merely concede that technological change inevitably demands a re-appraisal of ideas on operator selection, training, and supervision. However, there has grown out of this general thought a popular, although in the authors' opinion ill-founded, belief that in modern industry an operator can be assumed to be thinking about his process if he is not seen to be working on it. It would be unfair to suggest that either management or men would necessarily phrase this belief in such unequivocal terms, but there does seem to be a tendency for this industrial mythology to colour many people's views on the subject.

The work reported in this paper did a great deal to get the picture into perspective in I.C.I. There is no doubt that significant decision-taking loads are imposed on certain operators, but by and large the experiment indicated that the mental activities of process operators are much less than is popularly believed. This is not to say, of course, that no thinking is done! To run a chemical plant with operators who are incapable of taking any but the simplest decisions is inconceivable. But in practice, in a stable manufacturing process, the mental load of reasoning and taking decisions often falls on the supervisor rather than the operator. It seemed, in fact, that once a certain degree of plant instrumentation and automatic control had been reached, the mental load on the operator was often much lower than the load imposed by less elegant processes which required the operator to exercise direct control.

So it appeared that, in some types of process and in some supervisory situations, a quantitative expression of mental load on the operator was of little importance. It was clear, on the other hand, that mental load and physical work load do not give a complete picture of the total contribution which operators are expected to make towards the achievement of objectives specified by management. That is, the experiment's attempts to *quantify* non-physical components of total contribution, had underlined the importance of the *quality* of these components. Although an operator may be required only infrequently to make a major decision, his potential contribution is largely influenced by his ability and willingness to take appropriate thought and action during unsteady operating conditions and in cases of emergency. He must therefore have the proper attributes of character, intelligence, and skill, to enable him to recognise the infrequent need for a decision and to reach a sound one. And, of course, he must be in an organisational situation which motivates him to do so. This attempt to quantify the mental contribution required of process operators, therefore, indicated another very important area for further field research; that is, the area of character requirements without which the operator's physical and mental abilities are of little value to industry.

The authors are indebted to the many people in I.C.I. Ltd., whose hard work made this paper possible. In particular they wish to mention Mr. W. B. Stead, Work Study Manager of the Alkali Division of I.C.I. Ltd., whose diligence and patience as operational leader of the trials directing group was an inspiration to all his colleagues.

Cet article présente une étude réalisée par la Société " Imperial Chemical Industries " qui concerne la composante non-physique du travail chez des ouvriers de l'industrie chimique. En partant d'une étude de poste détaillée et d'une échelle de classification des types de charge de travail mental, il a été possible d'élaborer un procédé d'approche. On a étudié un système de notation par points afin de pouvoir quantifier ces types de charge de travail mental. Au cours de l'expérimentation, le procédé initialement élaboré s'est transformé en une méthode d'analyse des situations de prise de décision et en un moyen empirique de comparaison quantitative de telles situations. L'approche proposée entre essentiellement dans le cadre d'une étude expérimentale des situations de travail réelles. L'expérimentation aboutit à une clarification des idées relatives à la composante non-physique du travail et suggère des indications pour des recherches ultérieures.

Dieser Artikel beschreibt Untersuchungen der Imperial Chemical Industries als Teil einer Studie der nicht-körperlichen Beanspruchung von Arbeitern, die bei chemischen Prozessen tätig sind. Versuchsweise wurde ein Verfahren entwickelt, das auf einer detaillierten Untersuchung der Arbeitsplatz-Anforderungen und einer Methode der Klassifizierung von Typen der geistigen Belastung fusst. Im Verlauf der Untersuchungen ergab sich eine systematische Methode der Analyse von Situationen, in denen Entscheidungen zu treffen waren und ein Wertungsverfahren zum quantitativen Vergleich dieser Situationen. Das Vorgehen ähnelte grundsätzlich der Arbeitszeitstudie. Das Hauptergebnis der Untersuchungen bestand in einer Klärung der Vorstellungen über " geistige Anforderungen " und in Richtlinien für künftige Forschungsarbeit.

EFFECTS OF PUPIL APERTURE AND OF THE TIME OF EXPOSURE ON THE FATIGUE INDUCED VARIATIONS OF THE FLICKER FUSION FREQUENCY

By Etienne Grandjean and Etienne Perret

Department of Hygiene and Work Physiology of the Swiss Federal Institute of Technology, Zurich

Changes in Flicker Fusion Frequency (CFF) following performance of a mental task were measured on seven subjects using both an artificial pupil and normal vision, in order to see if these changes are due to modification of the pupil aperture following mental fatigue. Variations of CFF following a mental task were also studied in relation to the duration of the measures needed to establish CFF. Thirdly, the influence of an interruption of the intermittent light between two measures of CFF was examined.

The results show that (1) the artificial pupil lowered the CFF but did not influence its changes due to the mental task ; (2) lengthening the duration of measurement from 10 to 16 sec lowered the CFF and partially masked the effect of mental fatigue ; (3) the interruption of the intermittent light between two measures did not alter the CFF values significantly.

Replication of the measures on different days revealed a significant practice effect in that the CFF rose on the second day.

§ 1. Introduction

Many authors have studied the effect of fatigue on the flicker-fusion frequency (CFF). Some of their results have been summarized by Simonson and Brozek (1952). The data are given in Table 1, from which it may be seen that the findings are contradictory, some authors having found a decrease in CFF due to fatigue, others no variation at all, or at least none that was systematic.

These contradictions led us to study three questions :

1. *Might the decrease in CFF observed in certain states of fatigue be due to a narrowing of the pupil ?* Using drugs Speiser (1948) and Weekers and Roussel (1948) have shown, on the one hand that changes in the diameter of the pupil and of CFF go in the same direction, while on the other hand, it is known that fatigue corresponds to a parasympatheticotony, which in its turn may lead to a narrowing of the pupil, thus diminishing the quantity of light entering the subject's eye and consequently decreasing the CFF.

2. *Might the duration of the measures—i.e. the time required for measurement of CFF during which the eye is exposed to the intermittent light, be a factor influencing the variations of the CFF due to fatigue ?* Snell (1953) found that the longer the time of exposure the lower the CFF.

3. The last question arose from the results concerning question 2. As we shall see later, we found that the highest figures for, and the greatest decrease in, CFF were related to the shortest time of exposure we used. So we wondered if *interrupting the intermittent light between two measures in order to shorten the exposures would influence the CFF values.*

In addition we were able to examine whether or not practice has an influence on the CFF, by comparing the results of two sessions on different days, using the same subjects and experimental conditions on both.

Table 1. Effects of Several Activities on CFF

Author	Type of work	Mean CFF Changes (Hz)	Remarks
Graybiel *et al.* 1943	Daily work	No change	Normal work of pilots
Schmidtke 1951	Calculating (additions)	−5·4	Laboratory experiments for 3 hours
Schmidtke 1951	Microscopy	−5·3	id.
Schmidtke 1951	Reading	−0·9	id.
Schmidtke 1951	No work	approx. −0·8	From 8 a.m. to 5 p.m., 5 subjects
Simonson and Brozek 1948	Visual work	−1	Difficult visual tasks
Brozek *et al.* 1952/53	Clerical and laboratory	No change	
Ryan *et al.* 1953	Reading	Contradictory results	For $3\frac{1}{2}$ hours. Illumination 20 and 500 Lux
Busch and Wachholder 1953	Mental work	Decreases and	One day's studying
Busch and Wachholder 1953	Calculation (mental)	increases	During 70 to 90 min
Grandjean and Bättig 1955	Microscopy	−4	During 90 min
Grandjean and Bättig 1955	Reading	No change	Distance from text 1 m. 60 Lux
Grandjean and Bättig 1955	Righting needles	−2 to −4	According to experimental condition
Grandjean and Bättig 1955	Supervision	No change	Supervision without effort
Grandjean and Bättig 1955	Controls	−1·6	Controlling ampullas
Grandjean 1959	Telephonists' work	−2	Bad illumination. 3 hours
Grandjean 1959	Telephonists' work	−0·6	Day light. 3 hours
Grandjean 1959	Clerical	No change	For 4 hours
Rey *et al.* 1958	Fine mechanics	−1 to −12	According to occupation
Baron *et al.* 1958	Mecanography	−2·5	From 9 a.m. to 6 p.m.
Schmid 1960 a	Assembling	−0·5	From 9 a.m. to 5 p.m.
Grandjean and Jaun 1960	Telephonists' work	−1·3 to −2·1	Night work
Schmid 1960 b	Cooking and service in a restaurant	No change	3 subjects had an increase, 3 a decrease in FFF
Werner and Grandjean 1960	Psychological tests	−1·0 to −1·1	$2\frac{1}{2}$ to 3 hours
Whittenburg *et al.* 1956	Vigilance task	−1·19	2 hours

§ 2. Method

For the determination of the CFF we used a light-stroboscope (Strobotac) giving red flashes of 10^{-4} sec duration. The test surface had an area of 1 cm^2 and was observed by the subject through a black tube 60 cm long, thus allowing no surrounding light to enter the subject's eye.

Seven male students aged 23–26 years were 'fatigued' by performing a task in which they were presented with series of 7 digits written in a random order (e.g. 5 0 1 7 4 8 6), and were required to write them down in the normal order (i.e. for the example given, 0 1 4 5 6 7 8). The test lasted for 30 minutes, and involved a very substantial mental effort. To raise the subjects' motivation they were paid in proportion to the amount of work done.

Before and after the test we measured the foveal CFF five times, starting at a given initial frequency and raising it regularly by 1 Hz/sec, until the subject ceased to see flicker. We then compared the means of the measures taken before and after mental work, by *Student*'s t-tests for matched groups.

Three series of experiments were made, each intended to answer one of the three questions asked at the outset of the study :

1. *Influence of pupil aperture.* In order to eliminate the possible influence of variation in the diameter of the pupil, we used an artificial pupil, 1·8 mm in diameter, placed in front of the subject's right eye, his left eye being covered by a metal plate. We determined the CFF five times before and after mental effort, both with and without the artificial pupil. The initial rate of flicker presented was 35 Hz in all cases.

2. *Duration of exposure.* For this variable we used normal vision and different initial frequencies, thus varying the time needed to reach the point of flicker fusion. The rates presented initially were 35, 25 and 15 Hz, resulting in mean times of exposure of about 10, 16 and 28 sec respectively.

3. *Effect of interruption of light between two measures.* Here the subjects were three females and one male working at our Institute. They did not perform the digits-ordering test, and we merely measured their CFF under two conditions—with and without interruption between each of the five measures—alternately on six consecutive days.

§ 3. Results

Experiment 1. *Artificial Pupil*

The results of the first series of experiments are shown in Fig. 1, from which it can be seen that the use of the artificial pupil lowered the CFF considerably. This was presumably due not only to the artificial pupil itself but also, as Baker (1952) and Ireland (1950) have shown, to the fact that with it the viewing of the luminous test-patch is monocular. This is of little importance here, since we are interested only in the modifications of the pupil aperture as due to fatigue. The difference between measures before and after the mental effort was highly significant ($p < 0.01$) with normal vision as well as with the artificial pupil—these differences were 0·96 and 0·86 Hz respectively. We may thus conclude that it is not a modification of the pupil diameter which causes a lowering of the CFF after mental effort.

Experiment 2. Duration of Exposure

Two facts are important in the results shown in Fig. 2. Firstly, we see that for durations of exposure longer than 10 sec the CFF is lowered. Secondly, it appears that the decline in CFF due to mental effort is statistically significant only for the shortest duration of exposure we used, i.e. 10 sec. From this we conclude that the duration of exposure does influence the CFF, lowering it and partially masking the effects of mental fatigue.

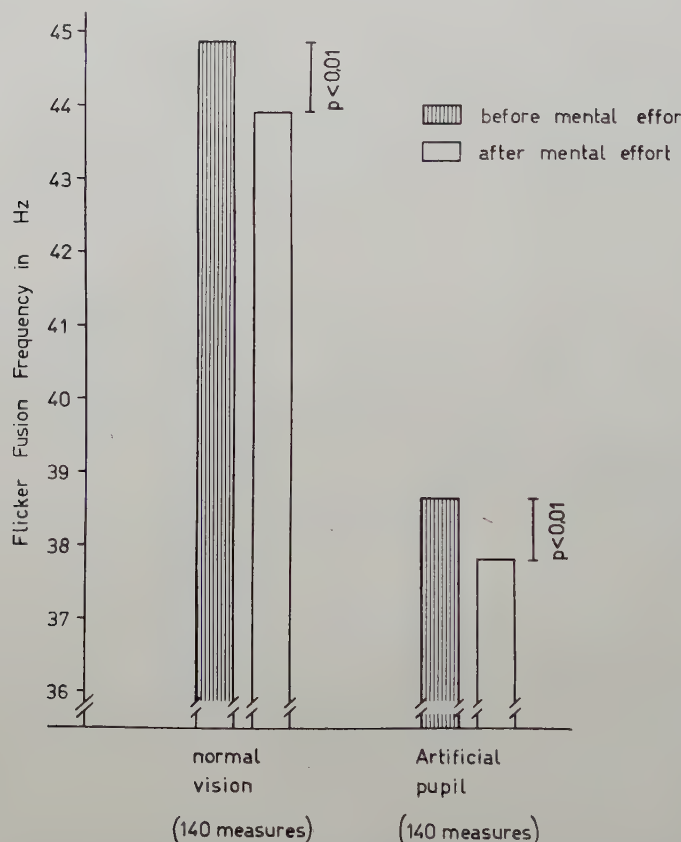
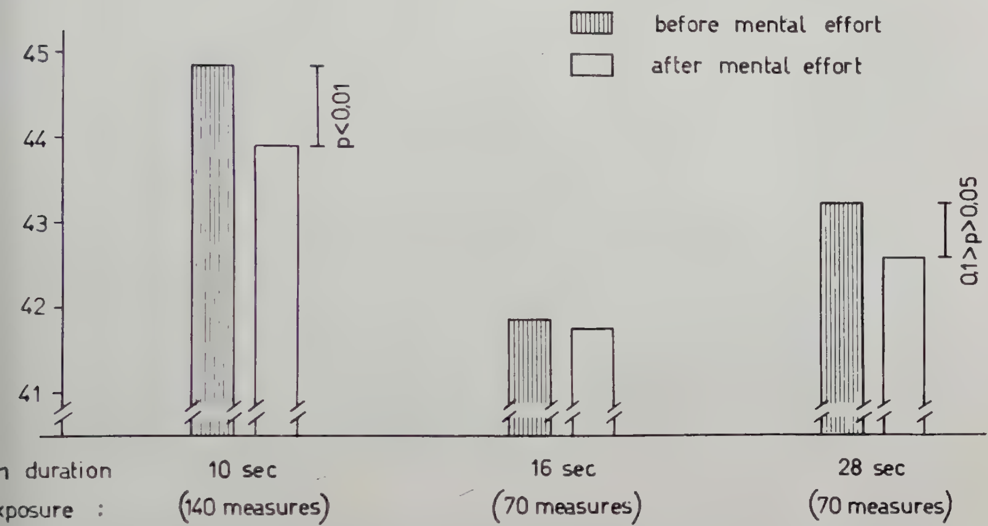


Figure 1. Flicker Fusion Frequency before and after mental effort, with normal vision and with artificial pupil.

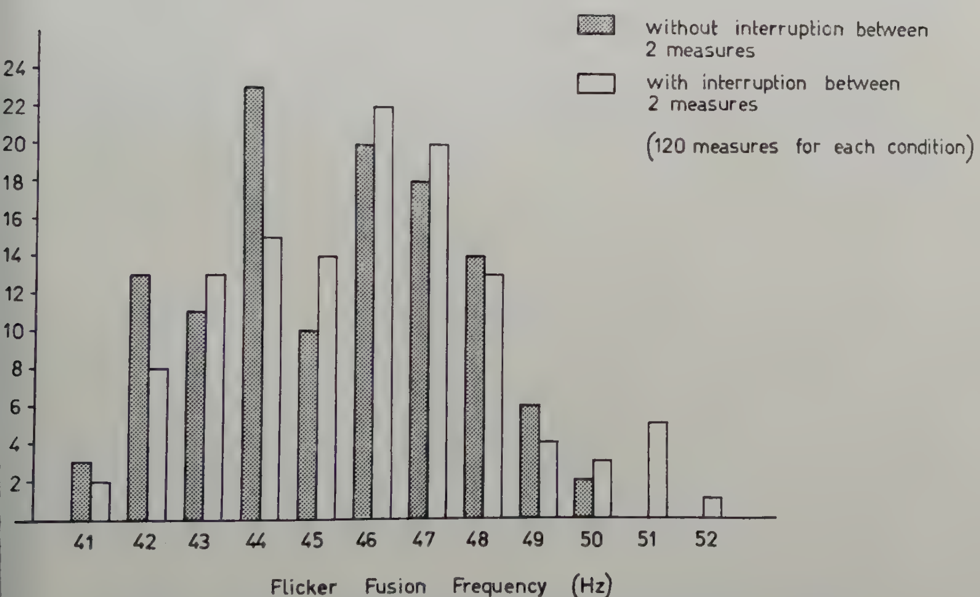
The obtaining of a somewhat higher CFF and greater difference between before and after mental effort for the third series of measures (28 sec) than for the second (16 sec), does not fit with this last conclusion. An explanation was, however, given by the subjects themselves : they knew that for the third series of measures the duration of exposure would be very long, and they therefore concentrated less on the luminous test patch, so avoiding continuous viewing of the flickering light during the 28 sec exposure preceding fusion. This shows once more the importance of subject's attitude in the measurements of CFF (see Simonson and Brozek 1952, Landis 1954). It appears from these results that the duration of exposure should be kept as short as possible when CFF is measured.

Experiment 3. *Interruption Between Measures*

Having found in Experiment 2 that the shorter the duration of exposure to ntermittent light the higher was the CFF and its variation following fatigue, ve wondered if interrupting the intermittent light between each of the five neasures, and so shortening the total time of exposure, would result in higher FF values. Figure 3 shows that the measures separated from each other by nterruption of the flashing light were slightly higher than those between which



igure 2. Flicker Fusion Frequency before and after mental effort, in relation to duration of exposure.



igure 3. Influence on Flicker Fusion Frequency of the interruption of the intermittent light between two measures.

there was no interruption. The average difference was 0·46 Hz which does not reach the level of significance. We think therefore that a continuous exposure strains the visual apparatus as much or just a little more than does an interruption between measures. This may be due to the retina having to adapt more frequently when interruptions occur than when the test light is present continuously.

Practice Effect

Some authors (Simonson and Brozek 1952, Landis and Hamwi 1954) have reported no variations—or at least no systematic ones—of CFF values with repetition of measurements, while others have found such variations. We found a highly significant difference ($p < 0 \cdot 01$), the CFF values of the second session being higher than those of the first, thus giving support to the observations of Landis (1954) and Speiser (1948).

Les variations de la Fréquence de Fusion (FF) dues à un effort mental ont été mesurées avec 7 sujets, avec pupille artificielle et en vision normale, dans le but de voir si ces variations proviennent de modifications du diamètre pupillaire dues à la fatigue mentale. D'autre part, on a étudié les variations de FF dues à un effort mental en fonction de la durée de la mesure. En outre, l'influence sur la FF d'une interruption de la lumière papillottante entre deux mesures a été examinée.

Les résultats montrent que (1) la pupille artificielle abaisse la FF mais ne modifie pas ses variations dues à un effort mental ; (2) jusqu'à 16 sec une durée de mesure prolongée abaisse les FF et masque partiellement l'effet d'une fatigue mentale ; (3) l'interruption de la lumière papillottante entre deux mesures ne modifie pas significativement la FF.

Enfin, les résultats obtenus montrent que la répétition des déterminations de la FF à différents jours produit un effet d'apprentissage, dans le sens d'une élévation de la FF.

Die Flimmerverschmelzungsfrequenz (FVF) wurde bei 7 Versuchspersonen vor und nach einer geistigen Anstrengung mit künstlicher Pupille und mit normaler Sicht bestimmt, um zu sehen, ob die Herabsetzung der FVF nach geistiger Ermüdung den Veränderungen der Pupillenweite zuzuschreiben sind. Weiter wurden die Veränderungen der FVF nach geistiger Anstrengung bezüglich der Dauer der Messungen untersucht. Ferner wurde untersucht, ob eine Unterbrechung des flimmernden Lichtes zwischen zwei Messungen einen Einfluss auf die FVF-Werte habe.

Die Ergebnisse zeigen, dass (1) die künstliche Pupille die FVF herabsetzt, aber keinen Einfluss auf die Veränderungen der FVF nach einer geistigen Anstrengung hat ; (2) bis 16 Sek Messdauer deren Verlängerung die FVF herabsetzt und den Einfluss der geistigen Ermüdung teilweise maskiert ; (3) die Unterbrechung des flimmernden Lichtes zwischen zwei Messungen die FVF nicht wesentlich beeinflusst.

Schliesslich erlauben es die Befunde, auf einen Einfluss der Wiederholung der Messungen an verschiedenen Tagen auf die FVF im Sinne einer Erhöhung zu schliessen.

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REHEARSAL AND RECALL IN IMMEDIATE MEMORY*

By A. F. Sanders
Institute for Perception, RVO–TNO, Soesterberg, The Netherlands

Experiments on the influence of rehearsal on the retention and recall of digit combinations are described, from the results of which it appears that a rehearsal period facilitates recall by producing a transition from immediate to permanent memory. It further seems that some parts of the material presented reach permanency very quickly, without much rehearsal, and also that mere transmission of material by the organism without intention to memorize it, nevertheless has some effect on material in the long-term memory store. It is argued that, during a rehearsal period, the main activity of the subject is not to repeat the material automatically, but to assimilate it with the conditional probabilities of past events.

§ 1. Introduction

During the last decade important research has been carried out on immediate memory and its functional meaning in human behaviour. Experiments have shown that it is useful to distinguish a short-term mechanism from a more permanent storage of information. The former may be thought of as closely connected with the perceptual system, while the latter forms a general background of experience and expectancy for the organism (Broadbent 1958). The material entering the immediate memory store is liable to a very rapid decay (Brown 1958, Conrad 1957), but can be maintained by continuous rehearsal. Relatively little work has been done, however, to determine what the effects of rehearsal might be on the transition of the material from the short- to the long-term store, or in more general terms, on learning. As Irion (1959) states : " If rehearsal, as a form of perseveration, has any effect upon post-rehearsal performance, it should be possible to treat it as an independent variable and to determine how it relates to other variables in the determination of learning performance. Far too little work has been done on this important topic." The general feeling, however, seems to be that rehearsal has a negligible effect on learning. For example, Brown states : " Everyday experience suggests that the effect of rehearsal may be to counteract decay of the immediate memory trace more than to strengthen it " ; and Woodworth and Schlosberg (1954) write : " If you look up a telephone number as Plaza 46315, you can repeat it easily a moment later because it falls within your primary memory span. If you wish to retain it for later use, you would gain very little by saying it over and over."

The experiments reported in this paper were designed to throw some light on this matter in relation to the following questions :

1. What is the effect on the stability of retention of inserting a rehearsal period between memorizing and recall ?
2. What are the characteristics of the transition from immediate to permanent memory ?

* This paper is based on one read to the Ergonomics Research Society on 29 March, 1960.

§ 2. Experiment I

A combination of eight digits (DC) was presented to the subject for 5 sec, in which time he had to memorize it. This was followed by a rehearsal period and a recall (R_{2a}, R_{1b}). Two conditions were compared :

A : Another recall (R_{1a}) was interpolated immediately after memorizing.

B : Only rehearsal occurred between memorizing and recall. The lengths of these rehearsal periods were respectively 35 and 40 sec.

The two conditions may be illustrated thus :

A : DC R_{1a} ——— 35 sec ——— R_{2a}
B : DC ——— 40 sec ——— R_{1b}

We should expect R_{2a} to be poorer than R_{1b}, since the material in the short-term store is supposed to deteriorate during the interpolated recall (R_{1a}) in condition A.

An answer to the first question, concerning the influence of rehearsal on the stability of retention, is provided by a variant of this experiment shown in the following plan :

C : DC ——— 12 sec ——— R_{1c} ——— 23 sec ——— R_{2c}
B : DC ——— 40 sec ——— R_{1b}

The interpolated recall (R_{1c}) in condition C is preceded by a rehearsal period, instead of coming immediately after DC as in condition A. The B condition serves as a control. If rehearsal merely counteracts decay of the immediate memory trace, we should expect again a deterioration at R_{2c}, as compared with R_{1b}. If, however, rehearsal also improves the stability of the material, the first rehearsal period of 12 sec should bring R_{2c} and R_{1b} nearer equality.

The digits were projected onto a screen and a mechanical device assured the constancy of the presentation time. Before each presentation and recall the subject was given a warning signal. The total time for one DC, within the described procedure took approximately 50 sec. Forty-four Air Force ratings served as subjects. Thirty-two were tested in the A and B conditions in a counterbalanced order. Twelve subjects were tested in the C and B conditions in the same way. All were instructed to memorize the digits in groups of two, e.g. forty-one instead of four one. Each subject was given ten different digit combinations in each of the two conditions. The score consisted of the number of mistakes made in reproduction, and every digit that was not reproduced in its right place counted as a mistake. For example, complete failure to answer a whole digit combination would have counted as eight mistakes. The mean numbers of mistakes per subject that were made are shown in the following plan :

A : DC R_{1a} 15·9 ——— R_{2a} 26·3
B : DC ——— R_{1b} 20·1
C : DC ——— R_{1c} 17·8 ——— R_{2c} 17·9
B : DC ——— R_{1b} 15·8

An analysis of variance of these data showed that in the first pair of conditions (A, B), there were significant differences between subjects ($F=6{\cdot}70$, $p<0{\cdot}01$), between trials ($F=10{\cdot}62$, $p<0{\cdot}01$) and between R_{2a} and R_{1b} ($F=16{\cdot}51$, $p<0{\cdot}01$). A t-test showed R_{2a} significantly different from R_{1a}.

Another analysis of variance failed to reveal a significant difference between R_{1a} and R_{1b}. For the second pair of conditions (B, C) there were no significant differences between recalls (R_{1b}, R_{1c} and R_{2c}) when the same statistical procedures were employed.

From these results it appears that the interpolation of a recall immediately after memorizing, has a detrimental effect on a later recall, compared with an interpolated rehearsal period. The effect seems, however, to be overcome if a rehearsal period precedes the interpolated recall as happened in the C condition. This appears to imply that the memorized material has been strengthened during the rehearsal period.

It should be mentioned in passing that the individual scores for the first pair of conditions (A, B) proved to be highly related to verbal intelligence-test performance, the less intelligent group performing worse at the memory tests than the more intelligent ($t = 4{\cdot}38$, $p < 0{\cdot}01$).

§ 3. Experiment II

In this experiment the effect of interpolated recall was studied more systematically. Again combinations of eight digits were presented for 5 sec. After presentation a recall was required every 4 sec until 10 reproductions (R_1 to R_{10}) had been given. Twenty-five new Air Force ratings were tested, to each of whom five digit combinations were given. They were instructed always to reproduce eight digits, even if they were not sure they were exactly

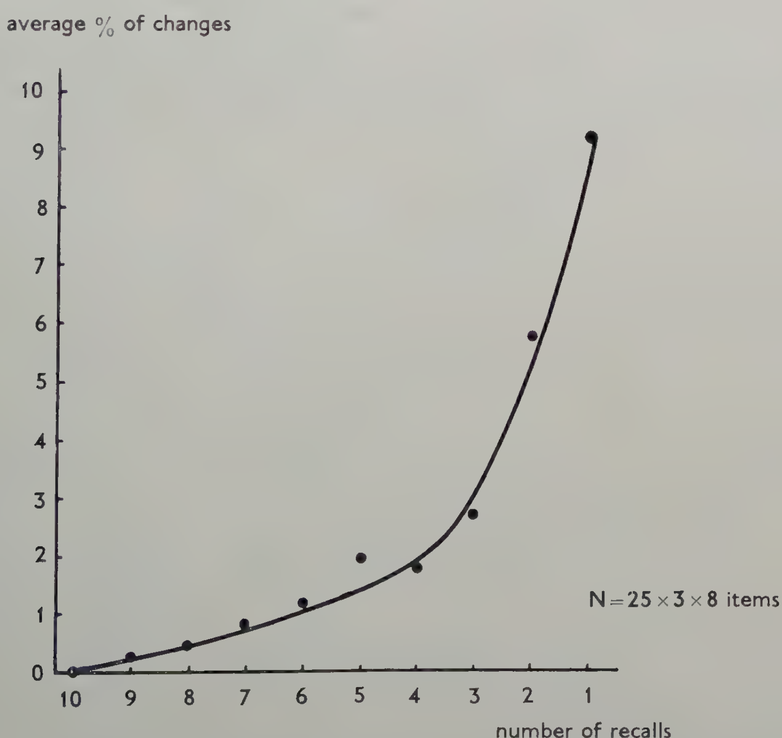

Figure 1. Mean percentages of changes between each recall and the next. (Experiment II.)

those of the original combinations. The scoring was done in terms of the amount of change between each recall and the next. Each digit not in the same place as in the immediately previous recall, was regarded as a change. The other details of method and procedure were the same as those of Experiment I.

It was expected that the rehearsal between recalls—and the recalls themselves—would strengthen the memory traces and result in progressively fewer changes between each recall and the next.

The mean percentages of changes are shown in Fig. 1. Applying analysis of variance to these results significant differences were found between recalls ($F=3{\cdot}15$, $p<0{\cdot}01$) and between subjects ($F=2{\cdot}09$, $p<0{\cdot}01$), while t-tests showed that significant differences between recalls stopped after the fourth recall.

There appears from these results to be a gradual tendency towards greater stability of the material with each successive rehearsal period and recall. That this cannot be solely due to the recalls as opposed to the rehearsal is indicated by the results of the ensuing two experiments.

§ 4. Experiment III

From the experiments reported so far we can conclude that, with rehearsal, some transition occurs from short- to long-term memory, but we cannot say what is the extent of the process or what are its characteristics. We can, however, obtain a measure of the degree of transition by means of the interference technique of Brown (1958). In this, information is presented, and immediately afterwards the subject is given another task, such as reading prose or digits aloud. The difference from traditional 'retroactive inhibition' techniques lies in the fact that no new memorizing is required. After completing the second task, the subject is asked to recall the original information. Brown found that as the quantity of material neared the limit of the memory span, the proportion retained became less.

Now it is possible to carry out such an experiment allowing rehearsal before interference. In fact Brown did this with rehearsal times up to 4 sec and found there was a significant improvement in performance. The present experiment was designed to extend his work to longer rehearsal and interference times.

Digit combinations were presented in the same way as in Experiments I and II. Subjects were allowed to rehearse them for some time after presentation, and then performed an additional task, which consisted of a quick reading aloud of digits from a Kraepelin test sheet. Just before starting the reading the subjects recalled the digit combination and this recall served as a criterion for a final recall after the reading had been completed. Before the test began subjects were asked to read out the Kraepelin digits at their fastest rate, and this was used as a criterion they were required to reach during the interference task. This was done to prevent rehearsal during the interference task. Sixty subjects were tested. Since intelligence had appeared in Experiment I to be an important factor in the memorizing process, students were used as subjects in order to prevent the occurrence of very low scores. The subjects were divided into seven groups. In three groups rehearsal was varied and interference held constant: in the others rehearsal was held constant and

interference varied. The times of both rehearsal and interference were as indicated in the following plan :

Group	Experimental Conditions	Times in seconds	Number of subjects
1.	Rehearsal varied :	40, 28, 20, 12, 8	10
	Interference constant :	120	
2.	Rehearsal varied :	28, 20, 12, 8	8
	Interference constant :	90	
3.	Rehearsal varied :	40, 28, 20, 12, 8	10
	Interference constant :	15	
4.	Rehearsal constant :	40	8
	Interference varied	120, 60, 30, 15	
5.	Rehearsal constant :	20	8
	Interference varied :	120, 60, 30, 15	
6.	Rehearsal constant :	12	8
	Interference varied :	120, 60, 30, 15	
7.	Rehearsal constant :	8	8
	Interference varied :	120, 60, 30, 15	

All tests within a group were performed by the same subjects in a Latin square arrangement. For each test, three digit combinations with the appropriate procedure were given, scoring was the same as in Experiment I.

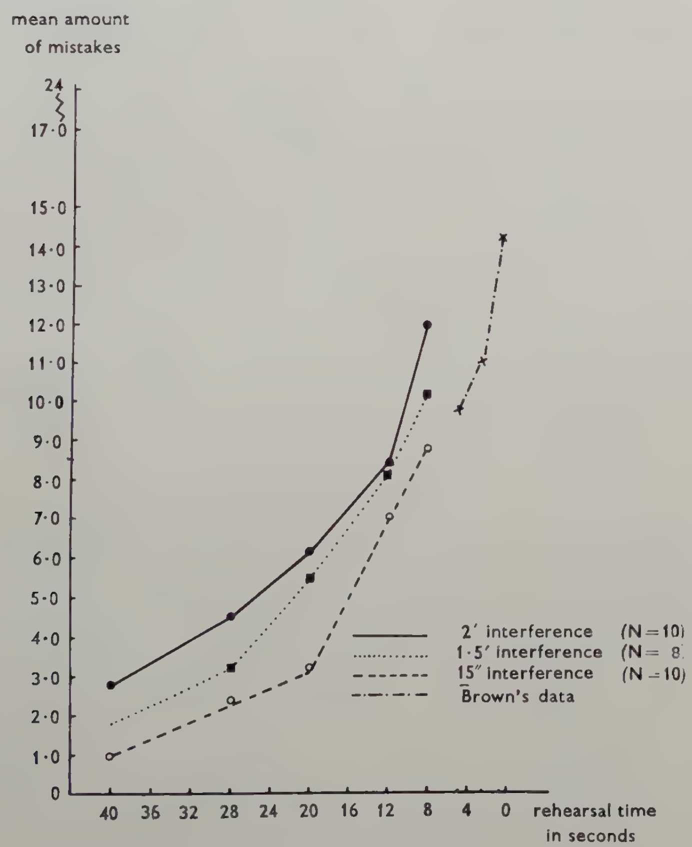

Figure 2. Mean numbers of mistakes made under conditions with length of rehearsal time varied and duration of interference task held constant. (Experiment III.)

The results of groups 1, 2 and 3, in which rehearsal times were varied while interference was held constant, are shown in Fig. 2. Analysis of variance on these results showed a highly significant difference between results with different times ($F = 10{\cdot}37$, $p < 0{\cdot}01$ at 120 sec interference ; $F = 8{\cdot}59$, $p < 0{\cdot}01$ at 90 sec interference and $F = 13{\cdot}7$, $p < 0{\cdot}01$ at 15 sec interference). Brown's data of 4 sec rehearsal with 7 sec interference have been transformed and included in this graph where, it will be seen, they fit very well.

The results of the remaining groups, in which rehearsal time was held constant and interference varied, are shown in Fig. 3. Analysis of variance showed significant differences between results with different interference times only when rehearsal times were 20 sec ($F = 8{\cdot}87$, $p < 0{\cdot}01$) and 12 sec ($F = 10{\cdot}7$, $p < 0{\cdot}01$). There were no significant differences with 40 sec and 8 sec rehearsal times.

It is clear from Fig. 2 that recall is better after prolonged rehearsal. We found in Experiment I that substantial benefit occurred after a rehearsal time of 12 sec, but this does not imply that the transition to the long-term store has been *completed* after 12 sec. Further rehearsal continues to improve recall of the digits. It is reasonable to suppose that we can get an idea of the actual stability of the material by examining the extent to which interference exerts an effect. Fig. 2, however, does not give satisfactory evidence on this point,

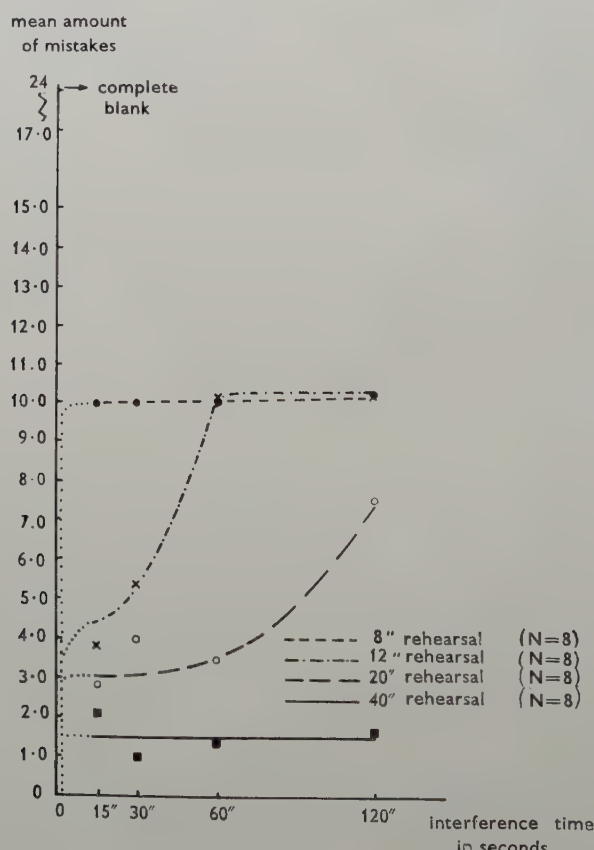

Figure 3. Mean numbers of mistakes made under conditions with length of rehearsal time held constant and duration of interference task varied. (Experiment III.)

because the different interference times were studied with different groups of subjects. The results for different interference times shown in Fig. 3 were, however, all obtained from the same subjects. These results seem to suggest three points about the transition of material from the short to the long term store, and also shed some light on the characteristics of the latter :

(*a*) When interference starts we can reasonably assume that the untransferred material still in the short term store, decays immediately. This is hypothetically indicated in Fig. 3 by the dotted lines drawn from 15 sec to 0 sec interference. The fact that plateaux exist in the graphs presumably indicates that the transferred digits have a fair permanency. This might serve as an additional argument for the functional distinction between the short- and the long-term stores, as retention in this study seemed to be of the all or none variety.

(*b*) With prolonged rehearsal the material is not only transferred but is also additionally strengthened in the permanent memory. Thus with 40 sec rehearsal time the trace is strong enough to stand 120 sec of interference. It cannot, however, do so with rehearsal times of only 20 or 12 sec.

(*c*) At first sight it is plausible to suppose that the decay in the long-term store reaches a maximum value with 12 and 8 sec rehearsal times. It appears however that it has not produced a complete blank. Since three digit combinations were presented in each test, a blank would have produced $3 \times 8 = 24$ mistakes. Allowing for chance, this makes approximately 22 mistakes. Yet even with 8 sec rehearsal time, the maximum number of mistakes averages no more than ten. The explanation of this is presumably that some parts of the material are placed very quickly and very firmly into the permanent store. We may reasonably suppose that these correspond most closely to the conditional probabilities of past events—or to express the point in mentalistic terms, those parts where some rule is evident to the subject are found easy to remember. Other parts of the material are more liable to decay, as is clear from the increase of mistakes with prolonged interference at 20 and 12 sec rehearsal times.

§ 5. Experiment IV

If we suppose that certain parts of the immediate memory load are very quickly transferred to the long-term store, it might be hypothesized that the former has an influence on earlier stored material in the latter, especially when the stability of the material in the permanent memory is not very high. The present experiment was carried out to test this hypothesis. The experimental scheme was thus :

1. DC_1 $\underline{\qquad\text{40 sec}\qquad}$ R_{DC1} DC_2 R_{DC2} R_{DC1}

2. DC_1 $\underline{\qquad\text{40 sec}\qquad}$ R_{DC1} LC R_{LC} R_{DC1}

3. DC_1 $\underline{\qquad\text{40 sec}\qquad}$ R_{DC1} (15 sec reading) R_{DC1}

4. DC_1 ______ 12 sec ______ R_{DC1} DC_2 R_{DC2} R_{DC1}

5. DC_1 ______ 12 sec ______ R_{DC1} LC R_{LC} R_{DC1}

6. DC_1 ______ 12 sec ______ R_{DC1} (15 sec reading) R_{DC1}

All conditions again started with an eight-digit combination (DC_1) presented for 5 sec. A rehearsal period of 40 sec for the first three and of 12 sec for the remaining conditions followed. The interference consisted of memorizing either a new digit combination (DC_2), or a letter combination (LC). In two conditions (3 and 6) subjects were asked to read digits from the Kraepelin sheet as a control. Immediately after the interference task a final recall took place. Where interference had consisted of a new immediate memory load, recall was first required of the new material. The interfering digit combinations consisted again of eight digits and the letter combinations of six letters. The subjects were instructed to recall this material as well as possible. Other details were identical with the previous experiments. Twelve new students performed all six conditions in a Latin Square order. In each condition two DC_1s were presented. The scoring was the same as in Experiment III. Just before the interference task the subjects were asked to recall the DC_1 and this served as the criterion for the final reproduction.

It was expected that the new memorized material (DC_2, LC) would exercise a negative influence on the reproduction of the earlier material (DC_1) especially when rehearsal had been relatively short, as in the 12 sec conditions. We were also interested in comparing the results of the digit and letter conditions, in view of the similarity of the former to DC_1.

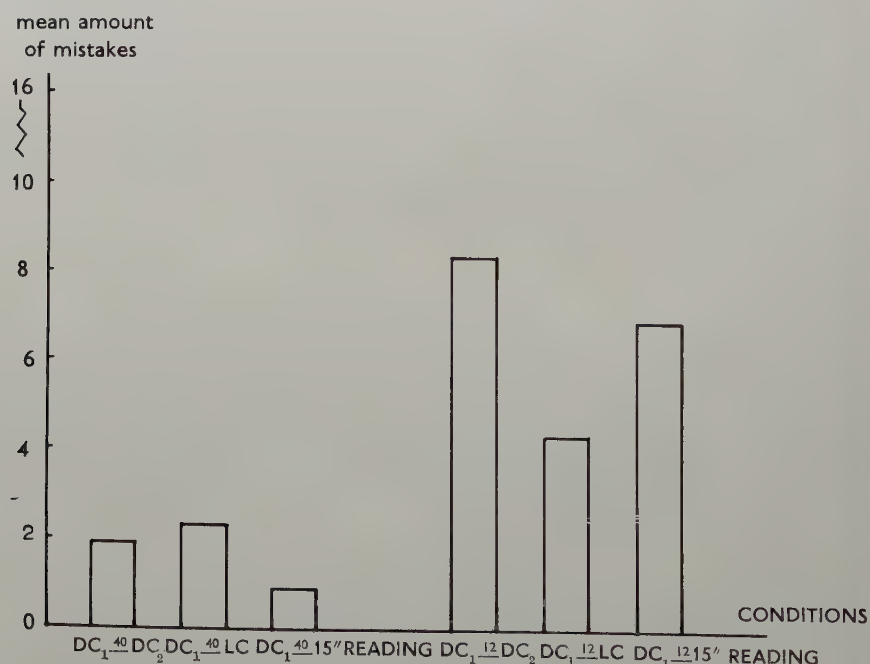

Figure 4. Mean numbers of mistakes made following different types of interference task and rehearsal times. (Experiment IV.)

The mean numbers of mistakes made under the various conditions are shown in Fig. 4. An analysis of variance showed significant differences between the conditions ($F = 16{\cdot}09$, $p < 0{\cdot}01$). Appropriate t-tests revealed that recalls after rehearsal times of 40 sec were generally better than after those of 12 sec. There was no evidence for significant differences within the 40 sec rehearsal time conditions, but in the 12 sec conditions performance after memorizing letters was better than after memorizing digits ($t = 4{\cdot}44$, $p < 0{\cdot}01$), and also better than after reading digits ($t = 2{\cdot}46$, $p < 0{\cdot}05$). The difference between performances after memorizing and reading digits was not significant.

The results for the 12 sec rehearsal times suggest that loading of the immediate memory directly affects the long term store. Memorizing new material which belonged to the same class as the material originally memorized had a clearly negative effect on retention of the original, and this ‘ retroactive inhibition ’ must presumably have taken place in the long-term store. The fact that the mere transmission of information that resembled the material to be recalled (i.e. reading Kraepelin digits) had a similar effect points to the conclusion that, whether or not memorizing is required, the permanent store plays a rôle in, and is influenced by, every intake of information especially when the material resembles very closely that which is already being carried in memory. The disappearance of the effects with 40 sec rehearsal time would be understandable if the material gained stability in the course of rehearsal.

§ 5. General Discussion

The results of the experiments taken together indicate strongly that rehearsal has a strengthening and stabilizing effect on retention of the kind of material used here. It seems doubtful, however, whether this improvement results from rehearsal in the sense of a mere automatic repetition, or indeed whether this kind of process is very important at all during rehearsal periods. Brown for instance, reported that several subjects tried to find interpretations for the letters he presented (e.g. National Debt for N.D.). This kind of tendency was noticed during our experiments and subjects also tried to impose rhythms and artificial rules on the material. In fact, the main activity of the organism during a rehearsal period seems to be the assimilation of the material by means of interpretation, imposition of rhythms, finding of rules, etc., to the conditional probabilities of past events in the long-term store. Only during the period immediately after memorizing a digit combination does rehearsal approach automatic repetition. We may, perhaps, suggest that as soon as some parts of the material are transferred, the immediate memory load is lessened and the repetition necessary to counteract decay of immediate memory becomes secondary to repetition aimed at long-term assimilation. In support of this view it may be noted that subjects tended to slow down their rehearsal rates after they had rehearsed for some time.

As we have seen, the mere transmission of information may have an effect on the long-term store. The effect is probably transitory in most cases though it may interfere with material which has been newly stored. Its effects appear to be less on material which has been rehearsed for a period and thus, presumably, strengthened and consolidated. It seems from observation that the long-term store may perhaps be subject to satiation in experiments like

this, so that retention of later digit combinations is hindered by the perseveration of earlier ones.

The results of these experiments do not agree with those of Conrad (1960), who found no strengthening effect of a 5 or 10 sec rehearsal period. There were however several differences between the conditions of his experiments and the present ones which might explain the discrepancy. For example, his rehearsal periods were very short compared with our experiments, and the presentation was auditory instead of visual. Also his subjects were not instructed to group the digits into pairs and they were perhaps somewhat less intelligent than ours—both factors which might have tended to a shorter immediate memory span.

The field seems ready for further experiments. Apart from testing the hypotheses made in this discussion, the question arises of how the mode of transition to the permanent memory relates to what is found in traditional learning experiments and phenomena of inhibition in that field.

I am indebted to Drs. E. W. J. Zwaan for help with testing subjects.

Les expériences décrites dans le présent article étudient l'influence de la répétition sur le souvenir et le rappel de combinaisons de chiffres. Il s'avère qu'une période de répétition facilite le rappel en créant une transition entre la mémoire immédiate et la mémoire différée. Il semble, en outre, qu'une certaine partie du matériel présenté atteint très rapidement un degré de permanence, sans beaucoup de répétition ; de même, la simple transmission de matériel par l'organisme, sans intention de le mémoriser, influence à un certain degré le matériel déjà enmagasiné dans la mémoire différée. On démontre que pendant la période de répétition, l'activité principale du sujet ne consiste pas à répéter automatiquement le matériel, mais à l'assimiler tout en tenant compte des probabilités conditionnelles afférentes aux évènements du passé.

Es werden Experimente über das Festhalten und Wiedererinnern von Zahlen-Kombinationen beschrieben, aus denen hervorgeht, dass das Wiedererinnern durch einen Uebergang aus dem Kurz-Gedächtnis in ein bleibendes Gedächtnis erleichert. Es scheint ferner, dass ein Teil des dargebotenen Materials sehr rasch, ohne viele Uebung, bleibend festgehalten wird, und dass auch die blosse Uebernahme von Material in den Organismus, ohne Absicht eines Erinnerns, das Material in langfristigen Gedächtnis-Vorrat beeinflusst. Es wird argumentiert, dass die Hauptsache bei der Uebung nicht die automatische Wiederholung eines Materials ist, sondern dessen Verbindung mit den bedingten Wahrscheinlichkeiten vergangener Ereignisse.

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MEASURING THE SPARE 'MENTAL CAPACITY' OF CAR DRIVERS BY A SUBSIDIARY TASK

By I. D. Brown and E. C. Poulton

Medical Research Council, Applied Psychology Research Unit, Cambridge

It is impossible to determine the degree to which a driver is absorbed in his driving by measuring his overt responses directly. However, relatively small changes in his spare 'mental capacity' can be detected by scoring his performance on a subsidiary task, which has no adverse effect upon driving. This technique is sufficiently sensitive to reveal the higher level of concentration required in a shopping area as compared with that required in a residential area.

§ 1. Introduction

Different levels of traffic demand different degrees of mental concentration from the car driver. This paper reports what is believed to be the first attempt ever made to measure the mental concentration in driving by giving the driver a subsidiary task to perform when he can. This technique resulted from early work on the division of attention and was used by Bornemann (1942 a and b) to study interactions between a subsidiary task of mental addition and a wide range of primary tasks. It has since been used to study 'automatization' of performance resulting from practice (Bahrick *et al* 1954, Bahrick and Shelley 1958, Broadbent 1956 a), to determine the relative difficulty of listening tasks (Broadbent 1956 b), to measure the order of difficulty of visual-motor tasks (Poulton 1958) and to compare man-machine tracking systems (Garvey and Taylor 1959). The theoretical basis of the technique is ". . . the assumption that there is a limit to the rate at which an operator can deal with information—in other words he has a limited 'channel capacity'. When the demands of the primary and subsidiary tasks together exceed this limit, errors must occur" (Poulton 1958, following Broadbent 1956). If the demands of the subsidiary task remain constant, these errors must reflect fluctuations in the demands of the primary task, in this case the driving.

The aim was to determine whether the technique is suitable, by the criteria of sensitivity and safety, for use in field studies of driving. If so, it offers a new approach to the measurement of the difficulty of driving, which can be related to the amount and type of traffic.

§ 2. Method

Two groups, one of 'average' and one of 'advanced' drivers, were tested. The former was drawn from a population of research workers and technicians. The length of time for which they had held a licence to drive a car ranged from 1 year to 16 years, with a median of 7·5 years. Training had been received at a driving school (2), in the services (2), or from friends and relatives (3). Two of the subjects were female. The 8 'advanced' drivers were male members of the Traffic Department of the Cambridge City Constabulary. The length of time for which they had held a licence to drive a car ranged from 20 to 28 years, with a median of 23 years. All had passed the Advanced Driving Course held at Chelmsford by the Essex County Constabulary.

The primary task was to drive around a test circuit measuring 2·2 miles in the city of Cambridge. The circuit included 'residential' areas and 'shopping' areas, and these were the two main 'conditions'. 'Residential' areas, which

occurred at the beginning and end of the circuit, contained many moving and several parked cars, few pedestrians or cyclists, and no ' zebra ' crossings or T-junctions. ' Shopping ' areas contained many moving and parked cars, many cyclists and very many pedestrians. Six ' zebra ' crossings and a number of T-junctions occurred in this part of the circuit. Measurements of average speed and frequency of control movements made during the experiment indicated that the ' mental load ' was greater when driving in the ' shopping ' areas. It seemed likely, therefore, that the errors on a subsidiary auditory task would be higher in the ' shopping ' areas than in the ' residential ' areas.

The subsidiary task for the ' average ' drivers was basically the same as that described in detail by Poulton (1960). A Ferrograph magnetic-tape recorder carried on the front near-side seat of the car delivered 8-digit numbers, one group every 4 sec, at a comfortable loudness. Each number group differed by only one digit from the previous group. New digits from 0 to 9 were taken from random-number tables, and the serial position in which the new digit occurred was also randomized. The subject had to detect the new digit each time a group was delivered, and speak it during the gap of about 2 sec before the next group arrived. Responses were recorded as ' late ' if they started while the next group was being presented.

The ' average ' drivers practised the auditory task alone for spells of 10 min until their errors fell below 30 per cent. They then drove on minor country roads for spells of 15 min, during which the auditory task was again practised. This was repeated 3 times. Ten test runs in ' residential ' and ' shopping ' areas followed on different days. Finally the auditory task alone was repeated for 10 min. Two circuits were completed on each test run. The first circuit allowed the subjects to overcome, to some extent, the effects of transferring from their own vehicle to the experimental car. The subsidiary task was performed only on the second circuit, when incorrect and omitted responses were scored. The primary aim was not to compare driving with and without the subsidiary task, but to compare ' residential ' and ' shopping ' areas both when the subsidiary task was performed and when it was not. The time taken to complete each circuit was recorded.

The subsidiary task for the ' advanced ' drivers was mental addition. The tape recorder delivered 3-digit numbers at regular intervals and the subject was required to sum the digits and speak the total in the gap before the following group was presented. The time interval between number groups was adjusted to the ability of the individual. This was judged from a pretest with mental addition alone.

The pretest began with a series of twenty 3-digit numbers at intervals of 6·0 sec. The next twenty were given at intervals of 5·5 sec, and so on in steps of 0·5 sec, down to an interval of 3·0 sec. The procedure was repeated with the time interval increasing from 3·0 sec to 6·0 sec. The time interval used for each subject in the main experiment was the shortest at which only one error was incurred in a set of 20 additions. Each subject practised the mental addition alone for 10 min at this speed. Then followed the 10 test runs in ' residential ' and ' shopping ' areas. These were the same as for the ' average ' drivers, except for the different subsidiary task. Finally, mental addition alone was repeated for 10 min.

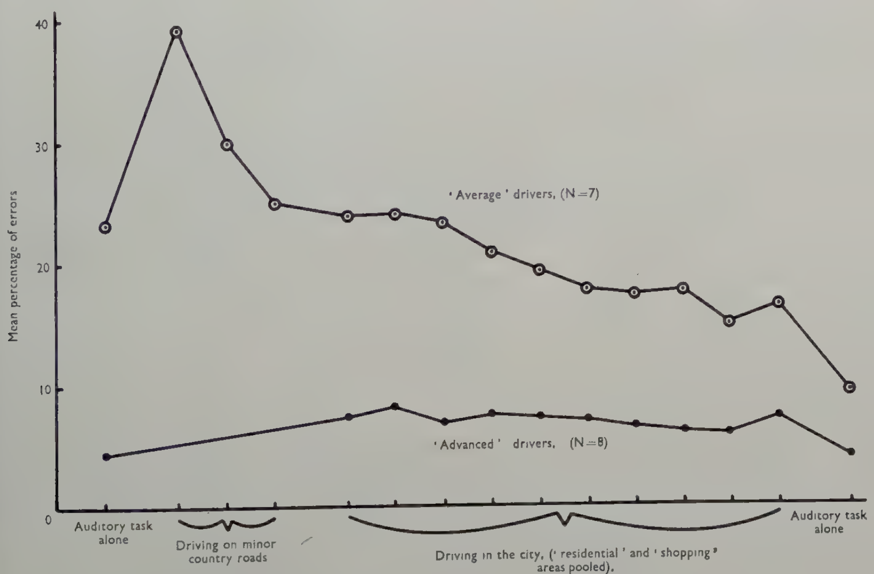
To prevent the subject conversing with the experimenter on the first circuit in 'residential' and 'shopping' areas when the subsidiary task was not presented, the subject was asked to drive at all times as he would normally if he were alone in the car. To emphasize the importance of maintaining a consistently high standard of driving, the subject was given the following instructions: "When the auditory task is presented on the second circuit try to maintain your normal standard of driving and, at the same time, try to make as few errors as possible on the auditory task. If driving conditions become so difficult that it is impossible to perform both tasks, concentrate on driving and resume the auditory task when it is possible and safe to do so. Do not attempt to obtain a low score of errors on the auditory task at the expense of a lowered standard of driving".

Events were recorded against time by a Gregory-Russell printing recorder carried in the boot of the car. For the advanced drivers, a switch fitted to the accelerator linkage was operated each time the pedal was reversed through more than 0·25 in. This event was printed automatically on the recorder. Errors on the subsidiary task, and the time of arrival at fixed points on the circuit, were also printed on the recorder. This was done by the experimenter, who was seated in the rear of the car, closing the appropriate switches.

§ 3. Results

3.1 *Changes in the Performance of the Auditory Tasks*

The figure shows the mean percentage of errors (i.e. responses which were either incorrect, late or omitted) incurred by both groups of subjects on the auditory tasks during the various stages of the experiment. For the 'average' drivers, a good deal of learning occurred during the three practice spells of driving in the country, and more occurred during the experiment proper. The 'advanced' drivers showed virtually no learning.



Trend of errors on the auditory tasks throughout the experiment.

Table 1. Mean percentage of errors on the auditory task

Subjects	Task		Auditory task alone	Auditory task subsidiary to driving: In ' residential ' areas	In ' shopping ' areas
' Average ' drivers (N=7)	Discrimination of changes in 8-digit numbers	Mean	9·4	16·2	20·5
		S.D.	9·5	8·8	11·3
' Advanced ' drivers (N=8)	Mental addition	Mean	4·1	6·3	7·3
		S.D.	2·0	3·4	3·3

The main comparisons are shown in Table 1. For the ' advanced ' drivers the score given for the auditory task alone is the average of the scores before and after driving. This is not the case for the ' average ' drivers, since a good deal of learning occurred between the initial test and the 10 experimental runs (see Fig. 1). Their score for the auditory task alone is that from the final test only. The scores while driving are the means from the 10 circuits which each subject made in ' residential ' and ' shopping ' areas while performing the auditory task.

For both groups the average percentage of errors incurred while driving in ' shopping ' areas showed a significant increase over those in ' residential ' areas, ($P < 0{\cdot}025$, Wilcoxon test, see Siegel 1956, p. 75).

The ' advanced ' drivers made significantly more errors in the ' residential ' areas than when performing the auditory task alone ($P < 0{\cdot}005$). To carry out a valid test for the ' average ' drivers, a regression line was fitted to the 10 successive scores of each subject for the ' residential ' areas only. By extrapolation, a score of percentage error was arrived at which would have been expected in ' residential ' areas if the previous rate of learning had continued into an imaginary eleventh test period, corresponding to the point at which the final auditory task was performed alone. The average value of this calculated score for ' residential ' areas (13·9 per cent), was significantly higher than the average score of 9·4 per cent on the final auditory task alone ($P < 0{\cdot}01$).

Both forms of the subsidiary task thus appear to be sensitive to the changes in ' mental load ', both from ' no driving ' to ' driving in residential areas ', and from ' driving in residential areas ' to ' driving in shopping areas '.

3.2 *The Effect of the Subsidiary Tasks upon Driving*

Table 2. Average speeds in miles per hour with and without the subsidiary task

Subjects		First circuit without subsidiary task: In ' residential ' areas	In ' shopping ' areas	Second circuit with subsidiary task: In ' residential ' areas	In ' shopping ' areas
' Average ' drivers: (N=7)	Mean	15·7	11·9	15·8	12·4
	S.D.	0·9	0·9	0·6	0·9
' Advanced ' drivers: (N=8)	Mean	16·3	12·2	16·5	12·1
	S.D.	1·2	1·5	1·7	0·4

The average speeds of the two groups of subjects, with and without their subsidiary auditory task, are shown in Table 2. Because the subsidiary task was always given on the second circuit, any effect it may have had upon driving is confounded with possible effects of familiarization with the car. However, it is possible to make a valid check that the smaller percentage of errors on the subsidiary task in the ' residential ' areas, as compared with the ' shopping '

areas, was not balanced by a corresponding change in the method of driving. Table 2 shows that, for both groups of drivers, average speeds in the 'shopping' areas were about 4 m.p.h. slower than in the 'residential' areas, both with and without the subsidiary tasks ($P<0{\cdot}01$). The increase in errors on the subsidiary tasks in the 'shopping' areas was thus not associated with any change in the rate of driving which did not occur also without the subsidiary tasks.

Table 3. The mean numbers of reversals of the accelerator pedal per 100 yards with and without the subsidiary task

Subjects		First circuit without subsidiary task: In 'residential' areas	First circuit without subsidiary task: In 'shopping' areas	Second circuit with subsidiary task: In 'residential' areas	Second circuit with subsidiary task: In 'shopping' areas
'Advanced' drivers (N=8)	Mean	3·11	4·45	3·54	5·10
	S.D.	0·36	0·48	0·47	0·71

For the 'advanced' drivers only, the mean rate at which the accelerator pedal was reversed was recorded, with results shown in Table 3. Both with and without the subsidiary task, pedal movements were about 45 per cent greater in the 'shopping' areas than in the 'residential' areas ($P<0{\cdot}005$). Here also, performing the subsidiary task did not alter the difference found between 'residential' and 'shopping' areas without the subsidiary task.

The reduced speed of driving, and the increased movement of the accelerator pedal, in the 'shopping' areas as compared with the 'residential' areas support the contention that driving was more difficult in the 'shopping' areas.

It is not possible to tell from Table 3 whether the significant increase in pedal movements when the subsidiary task was being performed ($P<0{\cdot}05$), was due to the performance of this task or to the greater familiarity with the car on the second circuit. Performance of the subsidiary task could reduce the span of anticipation, and thus necessitate more movements of the accelerator pedal. This still needs to be investigated.

§ 4. Discussion

The main finding is that the subsidiary-task technique can be used effectively in field studies to measure the spare mental capacity of the driver. A measure of spare capacity is useful not only in assessing the difficulty of driving in different kinds and levels of traffic; it also offers a possible method of assessing the effect upon the driver of fatigue and small doses of alcohol, since a gradual reduction in spare capacity is to be expected in these circumstances. Work along these lines is now being pursued.

The average increase in percentage error which resulted from the difference between 'residential' and 'shopping' areas may appear to be small. However the indications are that the average change in 'mental load' which produced this increase was also small. On occasions the traffic in the 'shopping' areas was no heavier than in the 'residential' areas. In addition, when traffic was very heavy in the shopping areas there were periods when the car was completely stationary and conditions approached, very closely, those obtaining during the performance of the auditory task alone. The overall differences in average speed, and in the movement of the accelerator pedal, between the two conditions when the subsidiary task was not performed were only of the order of 35 to 45 per cent (see Tables 2 and 3).

The secondary finding, which is important both for the validity and for the practical usefulness of the method, is that the subsidiary tasks did not substantially affect driving. The subjects did not decrease speed when performing the subsidiary task, and it is possible that the increase in the number of reversals of the accelerator pedal which occurred with the subsidiary task was in fact due to greater familiarity with the car.

It would be unwise to draw any conclusions from the results as to the relative suitability of the two subsidiary tasks, because they were performed by drivers with different backgrounds of training and experience. An investigation into the relative merits of different types of subsidiary task needs to be undertaken.

This work was carried out under the general direction of Mr. D. E. Broadbent. Statistical advice was given by Dr. M. Stone. Thanks are also due to the Chief Constable of Cambridge, who kindly provided the 'advanced' drivers, and to those members of the Applied Psychology Research Unit who took part in the experiment. The co-operation of Insp. Patten, Sgt. Quinney, and other members of the Traffic Department of the Cambridge City Constabulary is gratefully acknowledged. The experimental car was provided by the Medical Research Council.

Il n'est guère possible d'apprécier le degré de concentration exigé par la conduite d'une voiture en n'ayant recours qu'à la seule mesure directe des réactions visibles du conducteur. On peut cependant discerner les faibles modifications qui interviennent dans la " capacité mentale " de réserve en étudiant les performances dans une tâche auxiliaire n'affectant pas la conduite. Cette méthode est suffisamment sensible pour mettre en évidence un degré de concentration plus élevé exigé lors de la conduite en quartier commerçant comparé à celui de la conduite en quartier résidentiel.

Es ist unmöglich, den Grad, bis zu dem ein Kraftfahrer in seiner Aufmerksamkeit durch das Fahren absorbiert ist, aus seinen unmittelbaren Reaktionen zu bestimmen. Man kann dagegen relativ kleine Abweichungen von seiner geistigen Leistungs-Reserve entdecken, wenn man seine Leistungsfähigkeit in einer Neben-Aufgabe prüft, die das Fahren nicht nachteilig beeinflusst. Diese Methode ist genügend empfindlich, um den höheren Konzentrationsgrad beim Fahren in einem Einkaufsviertel, verglichen mit dem Konzentrationsgrad beim Fahren in einem Wohnviertel, zu erfassen.

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THE EFFECT OF 'UNWANTED' SIGNALS ON PERFORMANCE IN A VIGILANCE TASK

By W. P. Colquhoun
Medical Research Council, Applied Psychology Research Unit, Cambridge

Performance in a task of visual vigilance in which both 'wanted' and 'unwanted' signals occurred was observed in an experiment in which signal frequency and wanted signal probability (ratio of wanted to unwanted signals) were varied independently. It was found that:

1. A sixfold increase in the probability that any signal occurring would be a wanted one resulted in a considerable improvement in the efficiency with which these wanted signals were detected, wheareas a similar increase in the frequency with which signals were presented produced no significant alteration in efficiency.
2. The improvement in performance appeared during the first ten minutes of the watch and remained in evidence throughout the session.
3. The improvement was most marked in the case of signals appearing near the periphery of the display.
4. Individual differences in detection efficiency were related to the frequency with which false reports were made.

Implications for the theory of vigilance behaviour, and the relevance of the results to the organization of monitoring work, are considered in the discussion.

§ 1. Introduction

'Unwanted' signals occur in most tasks of signal detection, both in the laboratory and in real life. In some cases these unwanted signals may be readily distinguishable as such, but in others they are sufficiently similar in appearance to the 'wanted' signals to make it difficult for the observer to discriminate between the two types. Thus the operator of a radar set must try to pick out genuine target-echoes from the clutter of noise and 'false returns' that appears on a cathode-ray tube; and the industrial inspector's efficiency depends on his ability to distinguish those faults that just exceed the tolerance limit for a given standard of quality from those which may be just acceptable in the product.

The possibility that the occurrence of unwanted signals may affect the efficiency with which wanted signals are detected has been noted by Mackworth (1957), who suggests the need for research into three aspects of the unwanted signals—their frequency, their regularity, and their degree of similarity to the wanted signals. The first of these aspects was investigated in the experiment reported here.

To the best of the writer's knowledge there are no published reports of experiments in which the frequency of unwanted signals has been systematically varied. However, in almost all of the reported experiments on vigilance unwanted signals have appeared on the display in one form or another, and in two of these experiments (Jenkins 1958, Kappauf and Powe 1959) the frequency of these signals was inadvertently altered in a regular manner as a result of the controlled changes that were made in the frequency with which *wanted* signals were presented (wanted signal rate was the main factor studied in both of these experiments). The task used in these two investigations was of the kind in which the signals always appear at fixed, regular intervals throughout the test. Any increase in the number of wanted signals in this kind of

task can be achieved only by a corresponding *decrease* in the number of unwanted signals; in consequence, the probability that any signal appearing will be a wanted one rises as the number of such wanted signals increases.

Rises in wanted signal probability were also inadvertently induced by the increases in wanted signal frequency that were made in the two other reported experiments in this area (Deese and Ormond 1953, Bowen and Woodhead 1956), although here the changes in probability were smaller, because the actual *number* of unwanted signals was unaffected by the alterations in the wanted signal rate (there was no restriction on the total number of signals of any type that could appear in either of these studies).

In each of the four experiments cited above the efficiency with which wanted signals were detected rose as the number of these signals presented was increased. However, it is possible that this rise in detection efficiency was due, not to the increase in wanted signal *rate*, but to the accompanying increase in the probability that any signal would be a wanted one. An adequate theoretical interpretation of the results of these experiments cannot therefore be advanced until the relative importance of frequency and probability of wanted signals in determining detection efficiency has been established. The present investigation was designed to provide information on this point.

§ 2. Experimental Method

Apparatus

The apparatus in this experiment was a modified version of that used in an earlier study (Colquhoun 1959). A large wheel with a 7 in. face, rotating through 1/100 of its circumference at 2 sec intervals, presented a succession of displays in a viewing aperture placed at a distance of approximately 16 in. from the subject's eyes. Local illumination for the displays was provided from above by a shielded 60 w tungsten strip light; the rest of the experimental room was in semi-darkness.

Three kinds of display were employed. The first of these (' blank ') was simply the bare aluminium face of the wheel. The second (' unwanted ' signal) consisted of a black card on which was printed a row of six light-green discs*, each $\frac{1}{4}$ in. in diameter; the centres of the discs were $\frac{7}{8}$ in. apart. The third kind of display (' wanted ' signal) differed only from the second in that one of the discs was slightly " paler " than the remainder†. Directly beneath each position at which a disc appeared was a response key, operation of which was recorded.

Design

Performance was observed during a single continuous watch of 40 min. The numbers of wanted and unwanted signals presented during the watch varied according to one of three Conditions (see Table 1). In each Condition the remaining displays (of the total of 1200 presented) were blank.

Four hypotheses concerning detection efficiency in this kind of task are tested by this design.

* Munsell values: Hue 8–Gy; Chroma 2; Brightness Value 8.

† Munsell Values of Hue, Chroma & Brightness differed by less than half a single step from those for the standard discs, but the pale disc was readily identifiable, under the viewing conditions employed, by comparison with the remainder on the display.

Hypothesis 1 is that detection efficiency is determined by the *number of critical events* occurring during a session; the larger this number, the higher the proportion of wanted signals detected. This hypothesis predicts that the level of detection efficiency in Conditions I and III (144 critical events each) will be the same, and higher than the level in Condition II (24 critical events).

Hypothesis 2 is that detection efficiency is determined by the *number of wanted signals* presented; the larger this number, the higher the proportion of them detected. This hypothesis predicts that the level of detection efficiency in Conditions II and III (12 wanted signals each) will be the same, and lower than the level in Condition I (72 wanted signals).

Table 1. The three experimental conditions.

	Number of Wanted Signals	Number of Unwanted Signals	Wanted Signal Probability
Condition I	72	72	0·5
Condition II	12	12	0·5
Condition III	12	132	0·08

Hypothesis 3 is that detection efficiency is determined by the *number of unwanted signals* presented; the lower this number, the higher the proportion of wanted signals detected. This hypothesis predicts that the level of detection efficiency in Condition II (12 unwanted signals) will be higher than the level in Condition I (72 unwanted signals), and that this in turn will be higher than the level in Condition III (132 unwanted signals).

Hypothesis 4 is that detection efficiency is determined by the *probability that any signal appearing will be a wanted one*; the higher this probability, the higher the proportion of wanted signals detected. This hypothesis predicts that the level of detection efficiency in Conditions I and II (wanted signal probability 0·5) will be the same, and higher than the level in Condition III (wanted signal probability 0·08).

Signal sequence

Although, in each Condition, the overall statistical characteristics of the signal input were identical for all subjects, the actual sequence of displays presented differed in each individual case, being drawn up in accordance with the following rules:

1. In Conditions I and II, where the proportions of wanted and unwanted signals were equal, no more than two successive signals were of one kind. In Condition III, where there were 11 times as many unwanted signals as wanted ones, excessively long or short runs of unwanted signals were avoided.
2. In all Conditions the times of occurrence of signal displays were randomized, with the restrictions that the greatest time interval between successive signals never exceeded 10 times the smallest (minimum interval 6 sec.) and that each of the four 10 min. periods of the test was identical with respect to the numbers of signals of each type presented.
3. In all Conditions the locations of the pale disc on the wanted signals were randomized, with the restrictions that each of the six locations was represented an equal number of times during the session and that the disc never occupied the same location on more than two successive signals.

Subjects and procedure

Thirty-six young ratings of the Royal Navy with normal colour vision served as subjects. They were assigned at random in equal numbers to one of the three Conditions. Each subject was given an individual demonstration of the task, and was told that his aim should be to detect as many of the wanted signals as possible, while remembering at the same time that it was important to avoid reporting a signal when none was present (i.e. when an unwanted signal appeared). In order to ensure an adequate level of motivation, subjects were told that the results of the experiment would be directly applied to the organization of watchkeeping in the Navy. For discrimination training 24 signals were presented in succession at the viewing aperture. Twelve of these signals were wanted, the pale disc appearing at each of the six locations twice; the remaining 12 were unwanted. Subjects were required to depress the appropriate response key as quickly as possible when a wanted signal appeared, and to call ' same ' when all six discs were of identical colour. Knowledge of results, with correction where necessary, was given immediately after each response and before the next signal was exposed.

The experimental session (which was held a few days after the training described above) commenced with a short period of practice and special instruction. The wheel was first rotated at test speed through one complete revolution (100 displays) during which six wanted and six unwanted signals were presented. These signals were distributed among the blank displays in a manner which was random subject to the restrictions described previously. Subjects were required to report wanted signals as before, but were told not to respond in any way to the unwanted signals; they were informed of their scores at the end of this trial.

Subjects in Condition I were then told that during the subsequent test signals would occur at the same rate, and in the same proportions as they had just experienced. Subjects in Condition II were informed that, although the proportions of wanted and unwanted signals would be equal in the test, as they had been in the trial just completed, the signals themselves would occur many times less frequently. Subjects in Condition III were told that the proportion of wanted signals would be greatly reduced in the test; in order to ensure that this was fully understood, the wheel was turned through a further complete revolution during which a single wanted signal and 11 unwanted signals were presented (note: the wanted signal was successfully detected by all subjects given this trial).

The experimental session commenced at 10 a.m. for half the subjects in each Condition, and at 2 p.m. for the remainder. Experimenter and subject were separated by a screen during the test period and did not communicate at all. Watches were removed from subjects who wore them, and all subjects were told that the test would last for the best part of an hour.

§ 3. Results

There are two measures of performance to be considered. The first of these is the efficiency with which wanted signals were detected; the second is the frequency with which false reports were made.

3.1. *Detection Efficiency*

Initial level

The scores obtained from the practice trial that immediately preceded the test session indicated that the three groups of subjects were reasonably matched in detection skill following the standard training they had received earlier. The median number of wanted signals detected during this trial (out of a possible maximum of six) was five in each group; individual differences in efficiency were considerable, but comparable in range and distribution within each group.

Over-all test performance

In order to facilitate comparisons between the three Conditions, the number of wanted signals detected by each subject was converted to a percentage of the number presented to him; the resulting score was thus a measure of his detection efficiency. No significant difference, in any Condition, was found between the mean detection efficiency score for subjects tested at 10 a.m. and that for subjects tested at 2 p.m.; the scores were therefore pooled for subsequent analysis.

The mean detection efficiency scores in the three Conditions were: Condition I 79·7; Condition II 77·7; Condition III 61·8. The differences between the scores were found to be significant at better than the 2 per cent level of confidence (two-tailed test) in a Kruskal-Wallis one-way analysis of variance by ranks (Siegel 1956). It is clear that this result is due mainly to the difference between Condition III and the remaining Conditions.

The rank order of the mean scores conforms closely to that predicted by Hypothesis 4 (that the level of detection efficiency in Conditions I and II would be the same, and higher than the level in Condition III); Hypotheses 1, 2, and 3 are not supported by the results. Detection efficiency in this task in not, apparently, related either to the number of critical events, or to the number of wanted signals, or to the number of unwanted signals, but, rather, to the probability that any signal will be a wanted one. A sixfold increase in this probability produces a substantial improvement in detection efficiency which cannot be ascribed to the accompanying increase in signal *frequency.*

Within-session trends

There was a tendency for detection to become less efficient as the session progressed both in Condition I and Condition II (see Fig. 1). In order to test the significance of this decline in efficiency the slope of the within-session curve for each subject was estimated by the formula: $3(Q1-Q4)+(Q2-Q3)$, where $Q1 \ldots Q4$ are the detection scores for each of the 10 min periods 1 to 4. The resulting scores were cast into a frequency table for each Condition, according to whether their sign was positive or negative.

In Condition I the sign of the score was positive (i.e. a decrement occurred) in 10 of the 12 cases. By the sign test (Siegel, *op cit.*) the probability that this result would occur by chance alone is less than 0·02 (two-tailed test). In Condition II nine of the signs were positive; the effect here approaches significance by the same test ($P=0{\cdot}066$). No significant trend was found in Condition III.

It can be seen in Fig. 1 that the differences between the Conditions did not change in any systematic manner throughout the test session, and that even in the first 10 min period detection efficiency in Condition III was some 30 per cent lower than in either of the other Conditions.

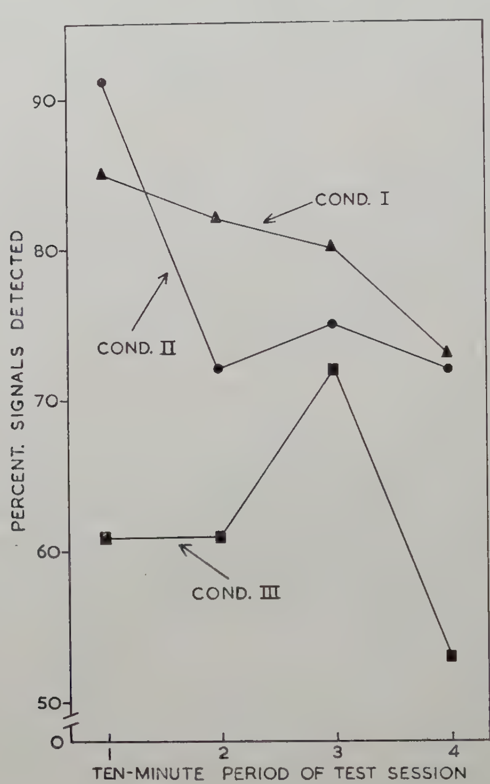

Figure 1. Average detection efficiency over all signal positions in successive ten-minute periods of the session.

Effect of signal location

Mean detection efficiency, in each Condition, varied according to the location at which the pale disc appeared on the wanted signal. The closer this was to the centre of the display, the higher the probability that it would be detected (see Fig. 2).

In an analysis of this location effect, 29 of the 36 subjects were found to have been more efficient at detecting the most centrally located pale discs (positions 3 and 4 in Fig. 2) than those sited at the ends of the display (positions 1 and 6). In the remaining seven cases there was no difference between the two scores. No subject showed greater efficiency at the end positions.

Of the 29 subjects whose scores showed a definite advantage for the central over the peripheral location, 23 gave scores at the intermediate location (positions 2 and 5) which were within the range defined by their own scores at the extremes, i.e. scores which are not inconsistent with the hypothesis that the effect of disc location is progressive over the range encompassed.

Figure 2 shows that there was little difference between the Conditions in the actual detection score returned for the most centrally located pale discs, but that as the lateral displacement of the disc from the centre increased, the

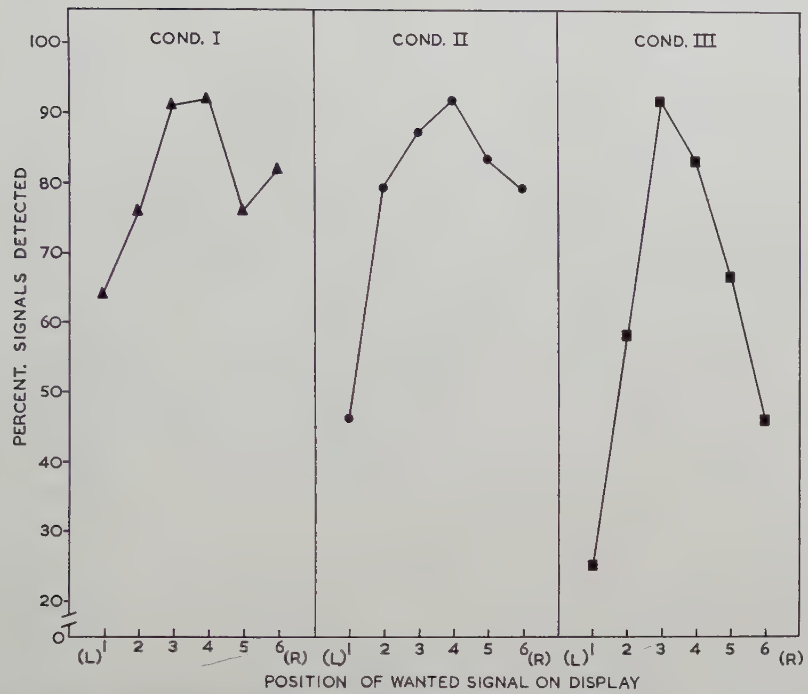

Figure 2. Average detection efficiency at each of the six signal positions over the whole session.

adverse effect of Condition III became progressively more pronounced. The mean percentage of wanted signals detected in each Condition at each degree of displacement is given in Table 2.

Table 2. Mean percentage of wanted signals detected at the different disc locations.

	Location of Pale Disc on Wanted Signal		
Condition	Central	Intermediate	Peripheral
I	91·3	76·0	72·9
II	89·6	81·3	64·6
III	87·5	62·5	35·4

The differences between the Conditions at the peripheral location were found to be significant at better than the 1 per cent level of confidence (Kruskal-Wallis test). At the intermediate and central locations the differences were not significant, but in both cases the detection score in Condition III was lower than that in either Condition I or Condition II.

As far as could be seen there was no systematic change in the disc location effect during the session, i.e. central discs were consistently detected more efficiently than peripheral ones, and the difference between Condition III and the remaining Conditions in the extent of this effect remained approximately constant.

3.2. *False Reports*

The number of responses to unwanted signals made by individual subjects varied widely. Fifteen subjects gave none at all throughout the session, and the frequency range in the remaining 21 cases was considerable.

Most false reports were made in Condition III, and the range of individual scores was greatest here also. Since least reports of either kind were made in this Condition, the percentage of all reports that was false was highest in this case. However, in the present experiment the incidence of false reports can only sensibly be considered in relation to the number of occasions on which it was possible to make one (i.e. to the total number of unwanted signals presented). The proportion of these occasions where a false report was made was approximately the same (3 per cent) in each Condition. The frequency of false reports tended to decrease during the test session; again, the rate of decrease was much the same in each Condition.

A positive rank correlation was found, within each Condition, between individual totals of detected signals, and the number of false reports made. In Condition I ' tau ' was 0·51, in Condition II 0·47, and in Condition III 0·25; the mean of these three values is 0·34, which is significant at better than the 2 per cent level of confidence (two-tailed test).

§ 4. Discussion

Theoretical implications

Theories of behaviour in vigilance tasks have been reviewed recently by Broadbent (1958). Four main theories can be distinguished—those of activation, inhibition, expectancy, and blocking or filter theory respectively. No distinction is made in any of these four approaches between the probable effects on detection efficiency of changes in signal frequency and signal probability. However, the evidence that has now been obtained of the importance of signal *probability* rather than signal frequency in determining efficiency in this kind of task raises difficulties for any interpretation of vigilance behaviour which fails to distinguish between these two characteristics of the signal. Why, for example, should an increase in the probability of a signal be more ' activating ' than an increase in its frequency?—or, alternatively, produce less ' inhibition ', even at the start of the test session? Why should expectancy concerning the onset of signals occurring at a given average rate be less accurate when these signals are made less probable?—and why should this difference in conditions be more likely to produce ' blocks ' or switches in attention? Future theoretical formulations must attempt to answer questions like these.

The fact that the adverse effect of low wanted signal probability was already evident during the first ten minutes of the test session indicates that the information about this probability that subjects were given before the test began was influencing their initial level of performance on the task (that signal probability can affect the threshold in psychophysical experiments has been shown by Howarth and Bulmer (1956)). It seems reasonable to suppose that, if this information had been witheld, the effect of probability would not have appeared until later in the test, when subjects had had sufficient experience of the test conditions to enable them to assess the actual state of

affairs for themselves. Thus the difference between the present result and those obtained by Jenkins (1958) and Kappauf and Powe (1959) (in both of which cases performance during the early part of the test was unaffected by wanted signal probability) may well be due to the fact that prior information was not given in these studies. Direct research, however, would be necessary to establish this point.

The finding that signals appearing near the edges of the viewing aperture were less readily detected than centrally located signals could be explained in terms of Baker's (1958) observation that, when a line display is continually scanned, the distribution of eye-fixations over the display must be centrally biased. However, recent demonstrations of the surprisingly small angular displacement that is required to produce a considerable rise in the brightness contrast threshold (Humphrey *et al.* 1960) would, in any case, lead one to expect some degree of ' peripheral blindness ' in the present task, in which the display subtended a visual angle of some 20°.

The fact that it was at the less efficiently monitored peripheral location that the effect of wanted signal probability was most evident confirms previous findings that signals of low detectability are more sensitive to changes in the level of vigilance than signals which are readily seen (Broadbent, *op. cit.*).

The incidence of false reports deserved some comment. The similarity between the rates with which these reports were made in the three experimental conditions suggests that this aspect of performance may not be affected by changes in either the frequency or the probability of wanted signals. The fact that false report rate was correlated with detection efficiency within each condition can be accounted for by the assumptions that, in signal detection tasks, the evocation of a ' wanted ' signal response depends on the occurrence within the observer of a critical level of appropriate neural activity (Tanner and Swets 1954), and that this level can differ in individual subjects. Where the criterion level is low, the probability of detecting a signal is high, but the chance of accepting a random fluctuation in the basic neural ' noise ' as a significant stimulus is considerable, and more false reports are therefore likely to be made than in the case where a stricter criterion is in operation.

Relevance to the design of monitoring work

The results discussed above suggest that efficiency at signal detection in most vigilance tasks will not necessarily be improved by the addition of extra (synthetic) signals unless these signals can be made to appear physically indistinguishable from the real ones. If this is not the case, the inclusion of the extra signals will lower the probability that any signal appearing will be of the kind that the subject is seeking, and the resulting effect may be the reverse of that intended. Thus in the experiment of Wallis and Newton (1957) the fact that the extra signals were readily seen to be synthetic may explain these authors' finding that the addition of these signals to the display did not produce any significant improvement in performance. The improvement observed by Garvey *et al.* (1959) may have been due to two special factors in their experiment: the extremely low wanted signal rate of only 2·5 per 2-hour period, and the fact that the subjects had to respond to the extra signals—the extra signals in this case are not ' unwanted '. The

exact range of conditions in which signal probability outweighs signal frequency in determining efficiency requires experimental determination; the present state of knowledge does not enable us to generalize beyond the relatively high input rates covered by the present investigation, in which it should be remembered that no response was required to the unwanted signals.

The implication of the results for the organization of inspection work in industry is that fault detection will not be improved simply by increasing the rate of flow of work to the examiner in order to raise the signal frequency, since wanted signal probability will be unaffected by such an increase. However, wanted signal probability could itself be increased considerably in many cases if the first-line inspector was required to reject *all* faults rather than only those of a certain degree of severity, the decision about acceptance or rejection being assigned to some higher authority.

The writer is grateful to Dr. M. Stone for statistical advice, and to the Royal Navy for supplying the subjects.

Dans l'éxpérience citée on étudie la performance dans une tâche de vigilance visuelle. Les signaux présentés comportent à la fois des signaux à " vigiler " (" attendus ") et des signaux à négliger (" indésirables "). On a fait varier la fréquence des signaux et la probabilité d'apparition des signaux à vigiler (rapport du nombre de signaux à vigiler au nombre de signaux à négliger) indépendamment l'une de l'autre.

Résultats :

(1) Une augmentation sextuple de la probabilité d'apparition d'un signal à vigiler améliore considérablement l'efficience dans la détection des signaux à vigiler, alors qu'une augmentation du même ordre de la fréquence de présentation de tous les signaux ne produit aucune modification significative de l'efficience.

(2) L'amélioration de la performance apparaît au cours des dix premières minutes de surveillance et se maintient tout au long de la passation du test.

(3) L'amélioration est la plus nette pour les signaux apparaissant près de la périphérie du dispositif.

(4) C'est la fréquence des réponses fausses qui rend compte des différences inter-individuelles.

La discussion traite des incidences des résultats sur la théorie du comportement de vigilance et de leur application à l'organisation du travail de surveillance.

Die Leistung bei einer visuellen Ueberwachungsaufgabe, bei der sowohl " erwünschte " als auch " unerwünschte " Signale auftreten, wurde in einem Versuch beobachtet, in dem die Signal-Frequenz und die Wahrscheinlichkeit der erwünschten Signale (das Verhältnis erwünschter zu unerwünschten Signalen) unabhängig verändert wurden.

Es wurde gefunden :

(1) Eine sechs-fache Zunahme der Wahrscheinlichkeit, dass jedes auftretende Signal ein erwünschtes sein wird, ergab eine erhebliche Verbesserung der Fähigkeit, erwünschte Signale zu entdecken, während eine ähnliche Zunahme der Signal-Frequenz zu keiner signifikanten Verbesserung der Leistungsfähigkeit führte.

(2) Die Verbesserung der Leistung erschien in den ersten 10 min der Ueberwachung und blieb während der ganzen Sitzung erhalten.

(3) Die Verbesserung war am deutlichsten, wenn die Signale am Rande des Beobachtungsfeldes erschienen.

(4) Individuelle Unterschiede in der Entdeckungs-Leistung standen in Beziehung zu der Häufigkeit falscher Angaben.

Folgerungen für die Theorie des Wachsamkeits-Verhaltens und die Bedeutung der Befunde für die Organisation von Ueberwachungsarbeit wurden diskutiert.

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THE ACCURACY OF SETTING OF MACHINE TOOLS BY MEANS OF HANDWHEELS AND DIALS

By E. N. Corlett

Department of Engineering Production, University of Birmingham

Experiments are reported which have studied the effects on the accuracy and speed of setting a dial to a pointer by means of a handwheel : a task simulating that of the operator of many machine tools. A marked rise of accuracy was found as the size of dial was increased from 2 to 8 in., and this was sufficiently consistent for a relationship of practical use to be formulated. Effects of changing the hand wheel diameter between 4 and 12 in. and the frictional torque between $7\frac{1}{2}$ and 60 lb in. were found to be negligible.

§ 1. The Problem and Approach

By far the greatest amount of work on handwheels has been to examine the influence of various factors on their effectiveness as tracking controls. This is a handwheel application very different from its use on a machine tool to set a cutter or workpiece to a desired position. In this latter situation work by Gibbs (1952) has produced a solution to the problem of the mental arithmetic involved when many turns of a spindle are required to produce a setting in accurate relationship to a previous setting. When the maximum speed of rotation through a half or full turn of a handwheel is required, Davis (1949) has provided results of laboratory experiments covering a variety of control types and positions. But if a criterion of consistency of setting is proposed, no results are directly available. The experiments described below were carried out in order to provide some information on the effect of handwheel size on setting accuracy.

If the available information regarding dials is surveyed, much the same picture is evident. The greatest amount of work has been on the accurate reading of dials or the setting of a pointer on a dial, in the latter case face dials being the main consideration. Where the dial is marked around its edge rather than on its face there are no research results available which apply directly to the machine tool setting problem.

One of the few studies throwing some light on the problems of accurate setting is work by Saldanha (1955, 1957). Subjects set a vernier caliper to values visually presented on demand over two periods of time. Results were assessed as the variance of the values set about the correct value. A deterioration between the two test periods was evident unless a complete rest had been taken, and deterioration between the first and second halves of each test period was very great. Some of the methodology, as well as the evidence of deterioration of performance, was used in the conduct of the experiments described here.

As stated earlier, it is considered that the criterion of success in the setting of a machine tool is consistent accuracy : the operator must be able to set the dimension he requires when he requires it. This has two aspects ; the ergonomic and the mechanical. Much work is in progress on the mechanical aspect of machine tool response: this paper is a description of attempts to determine some of the ergonomic factors.

The approach has been to model the performance of the apparatus closely on the lines of a machine tool, to use skilled as well as unskilled operators for the experiment, and to adopt criteria of measurement equivalent to the parallel industrial situation. Figure 1 shows an optical dividing head A, which was used as the basis for the test equipment, arranged to give an accurate indication of the amount of rotation of a spindle. This spindle was arranged

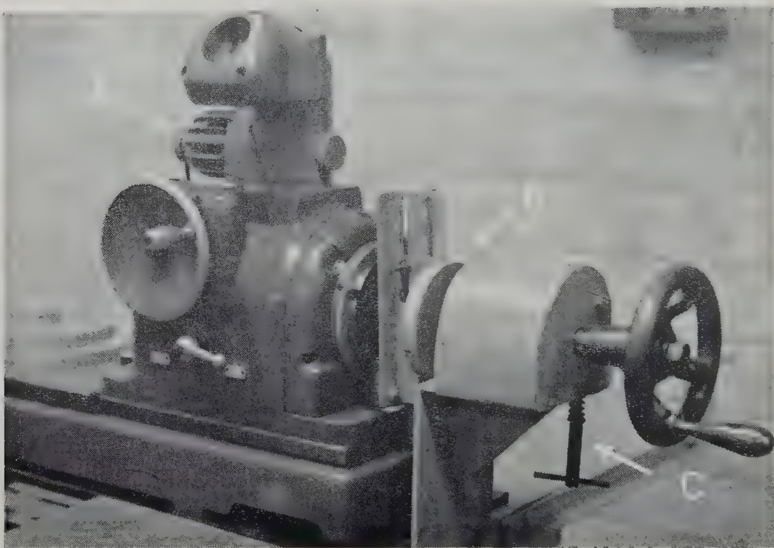


Fig. 1.

to receive various sizes of dial B and handwheel, and to suffer various amounts of frictional torque by means of screw C. The floor height was arranged to be variable to suit the height of the operator, the width of line on the dial was variable and the conditions of contrast of line and dial (grey anodised aluminium with a black line) and the general illumination (20 ft candles) were arranged to represent good industrial practice (Murrell 1957).

§ 2. A Preliminary Experiment

A preliminary experiment was conducted to examine the effects of the seven factors considered as relevant to the problem, and to determine which should be examined in more detail (Corlett and Gregory 1960). The method was to use a half-replicate of a 2^7 factorial design, it being confounded into 4 blocks of 16 experiments each. The factors considered as relevant were :

(*a*) Handwheel diameter.
(*b*) Dial diameter.
(*c*) Line thickness.
(*d*) Spindle friction.
(*e*) Working height.
(*f*) Experience of the operator.
(*g*) Knowledge of results.

The factors (f) and (g) were introduced since the design enabled this information to be obtained with little additional work, but the factor (f) was confounded with the blocks, its main effect being ignored but its effect on the other factors being preserved. The purpose of introducing factor (g) was to provide information for the conduct of the later experiments. It will be realized that an operator obtains his knowledge of results by measuring the part he is machining. As no measurements were possible by the subject on this apparatus the reading of the dividing head was told to him after each setting, enabling him to develop some idea of his performance of the task.

The subjects were told that they should set the dial to the line as accurately as possible by moving the handwheel in a clockwise direction, in the same manner and with the same accuracy as if they were setting the final cut on an accurate toolroom machine. and that they should repeat the setting if they were not satisfied with the original setting. It was emphasized that time was of no importance, but the time taken was recorded by a stop-clock. This was done because it seemed reasonable to suppose that from these instructions the operator would maintain the same consistency of setting regardless of the difficulties, and an indication of difficulty would appear in the length of time he took to obtain the setting he required. Variations in the consistency of setting could indicate a physical inability to realize the differences between one setting and another. If the line was overshot the wheel had to be reversed to well before the setting position and another approach made. Thus the conditions of backlash to be met on machine tools were simulated. After the finally set position had been recorded from the dividing head the experimenter recorded the overall setting time and reset the time clock, the audible click from this was the subject's signal to turn the wheel anti-clockwise and make another approach. The method of setting was left to each individual ; in fact, every subject tapped the rim or handle of the wheel. Each set of conditions was set 25 times by the subject and took up to 10 min to perform. A rest of about 5 min was taken whilst the next set of conditions was arranged on the apparatus. Thus it was hoped to avoid the deterioration found by Saldanha and, in fact, no trends attributable to a decline in performance with time were found.

Results of this survey experiment, conducted with one experienced machine operator and one inexperienced man, indicated that the most promising fields for further experiment would be the variation of

(*a*) Dial diameter and line thickness.

(*b*) Handwheel diameter and friction on the spindle.

The value at which the other listed factors should be held constant were shown to have little effect on the results. For instance, the effect of floor level was just significant in some interactions at the 5 per cent level, and in fact the higher working height (in which the operator's elbow is 6 in. above the axis of the spindle) was decided upon. Also, knowledge of results appeared to cause a less consistent performance from the skilled operator than no knowledge of results, although this, again, is only at the 5 per cent level. Thus it was decided not to give the dividing head readings to the operator.

§ 3. Main Experiments

The experiments based on the results of the first survey experiment tested five skilled and five unskilled subjects under the following conditions :—

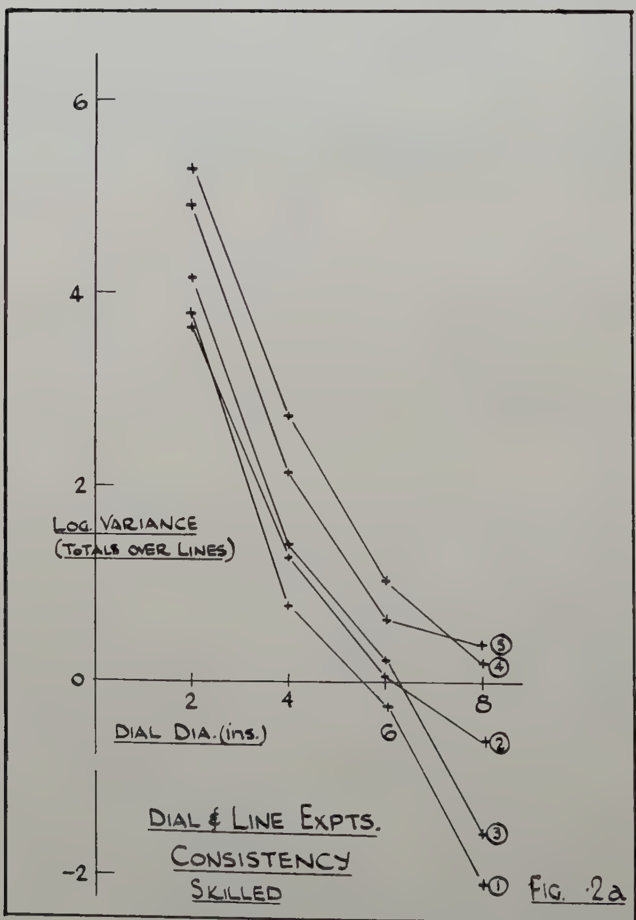
(*a*) a series of four different dial diameters, 2 in., 4 in., 6 in. and 8 in. diameter, each engraved with four black-filled lines of 0·008 in., 0·016 in., 0·032 in. and 0·064 in. wide, each with an 8 in. diameter handwheel and a frictional torque of 7½ lb in.

(*b*) a series of five different handwheel diameters, 4 in., 5½ in., 8 in., 10 in. and 12 in. diameter, working against frictional torques of 7½, 15, 30 and 60 lb in., each with a 6 in. diameter dial engraved with an 0·016 in. line.

Twenty-five readings for both the time and dividing head setting for each treatment were recorded.

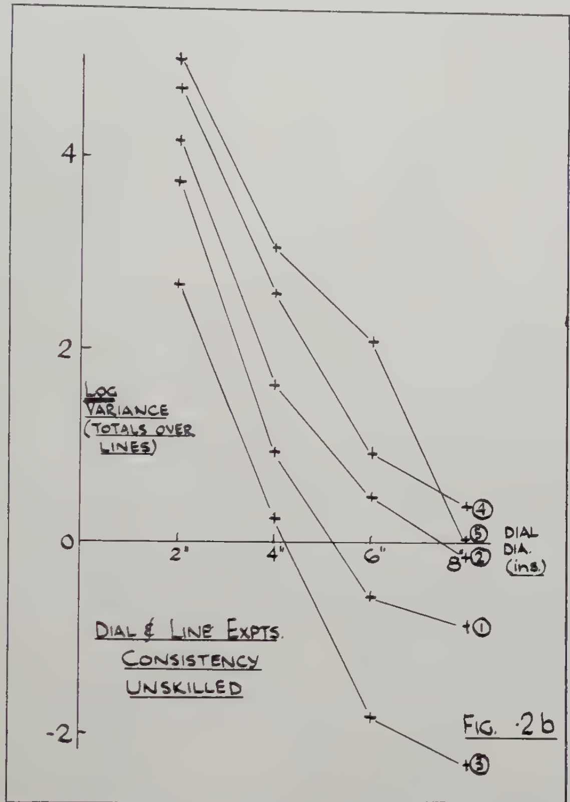
3.1. *Results for Condition* (*a*)

A summary of the results obtained from the experiments on different dial diameters and line thicknesses is given in Figs. 2 and 3 and Table 1.



The numbers in circles refer to the individual subjects.

Each point on each of these graphs represents the total of four quantities, those for the four line thicknesses. The ordinates of Fig. 2 thus show totals of logs of the variances of 25 trials at each of four line thicknesses. Figure 3 gives the totals of the means of the logs of the 25 time values recorded at each of these four line thicknesses. The very rapid increase in consistency as Dial



The numbers in circles refer to two individual subjects.

Diameter increased, is evident, but the almost exact coincidence between the skilled and unskilled subjects is surprising. The amount of improvement for each group was almost exactly the same as Dial Diameter increased. The times taken were also much the same for skilled and unskilled subjects and the low significance of 5 per cent was due to a small trend towards increased times for the larger dials. If ' time ' had been used as the criterion it would have indicated that the smaller dials were better, a suggestion that would have had unfortunate repercussions on the resultant accuracy. The fact that line thickness had no effect on consistency was not in accord with the subjective judgements of many of the operators.

The wide variation between individual subjects is nearly constant throughout the range of dials tested, but the spread of these individual differences is such that it brings the result of one subject on a 2 in. dial into the range of results achieved on a 6 in. dial. That the subjects retain such a constant ranking throughout the tests gives some justification for plotting an average performance as in Fig. 4. This graph is produced from an average of the

Table 1. Analysis of variance. Effects of dial size and line width. Condition (*a*)

	Skilled subjects						
	Consistency				Time		
	Degrees of freedom	Mean square	Variance Ratio	Significance	Mean square	Variance Ratio	Significance
Dials	3	6·0399	115·64	0·1%	0·0105	3·695	5%
Lines	3	0·0640	1·225		0·0010	0·35	
Subjects	4	0·5076	9·72	0·1%	0·1324	46·456	0·1%
D × L	9	0·0689	1·32		0·0037	1·295	
D × S	12	0·0505	0·97		0·0035	1·214	
L × S	12	0·0412	0·79		0·0018	0·62	
Residual	36	0·0522			0·0029		

	Unskilled subjects						
	Consistency				Time		
	Degrees of freedom	Mean square	Variance Ratio	Significance	Mean square	Variance Ratio	Significance
Dials	3	5·2459	114·5	0·1%	0·0115	3·605	5%
Lines	3	0·0191	0·42		0·0078	2·436	
Subjects	4	1·2712	27·755	0·1%	0·0649	20·34	0·1%
D × L	9	0·0862	1·882		0·0041	1·288	
D × S	12	0·0363	0·79		0·0026	1·208	
L × L	12	0·0681	1·49		0·0045	1·42	
Residual	36	0·0458			0·0032		

skilled subjects and all line thicknesses for each dial, the ordinate representing $2\sqrt{\text{mean variance}}$ and thus indicating a probability of setting within the given range. If values from this graph are considered in relation to the setting of a lathe cross-slide, where a leadscrew with 8 threads per inch is a usual value, simple calculation will show that for the 6 in. dial a consistency of positioning of less than 2/100 of 0·001 in. may be achieved if the machine elements are responsive enough. This represents an ability to distinguish and adjust the displacements between the fixed line and the line on the dial of the order of 0·002 in.

The absence of line effect in Table 1 should be noticed. This may be due to the coarseness of the differences between lines, and experiments using finer differences may show a trend. Most operators admitted a change in behaviour between the fine lines, which were viewed as a whole, and the thicker lines, which were aligned by one edge or the other. Thus the results may be not significant because two (or three) of the four lines were, in effect, fine lines.

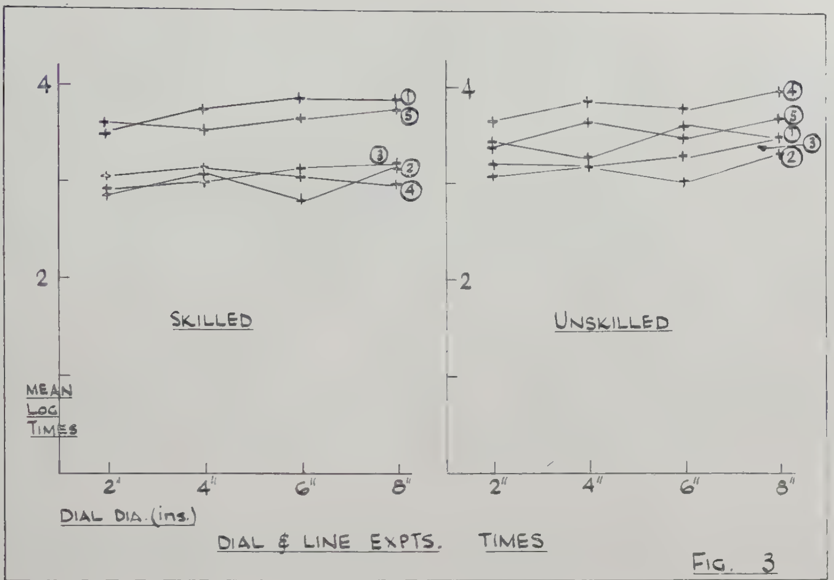

SKILLED
UNSKILLED
MEAN LOG TIMES
DIAL DIA. (ins.)
DIAL & LINE EXPTS. TIMES

Fig. 3

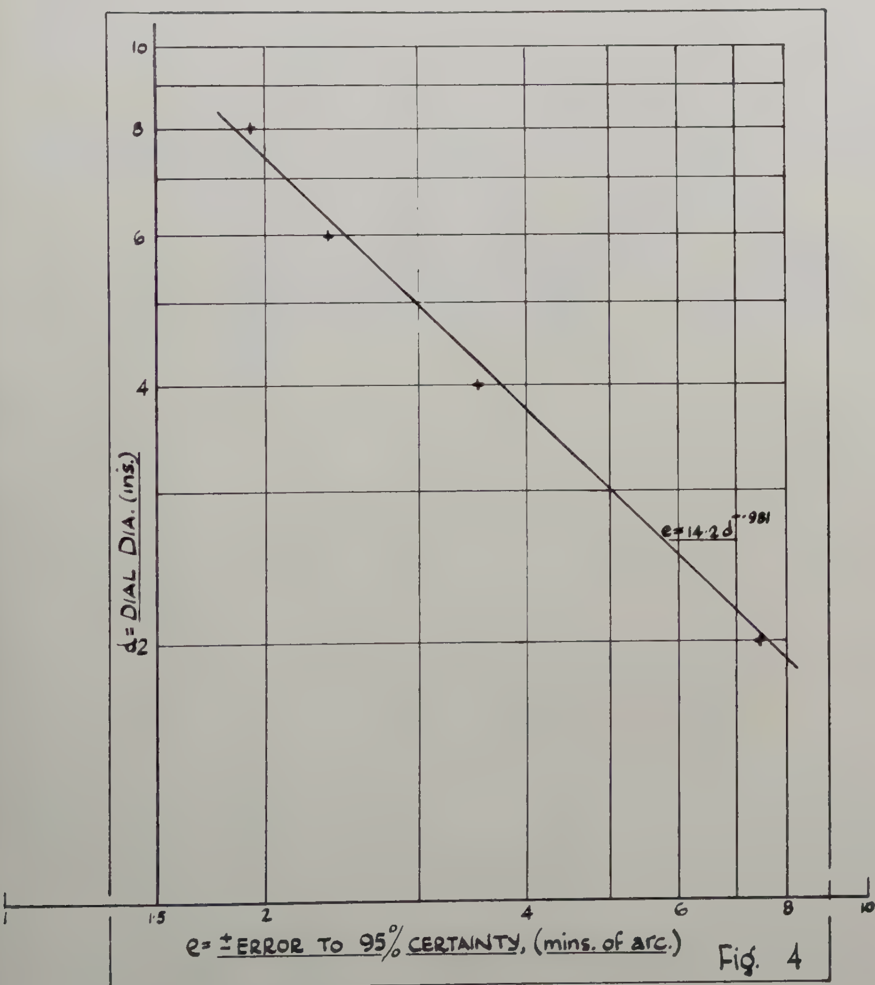

d = DIAL DIA. (ins.)
e = 14·2 d^-·981
e = ± ERROR TO 95% CERTAINTY, (mins. of arc.)

Fig. 4

3.2. *Results for Condition* (*b*)

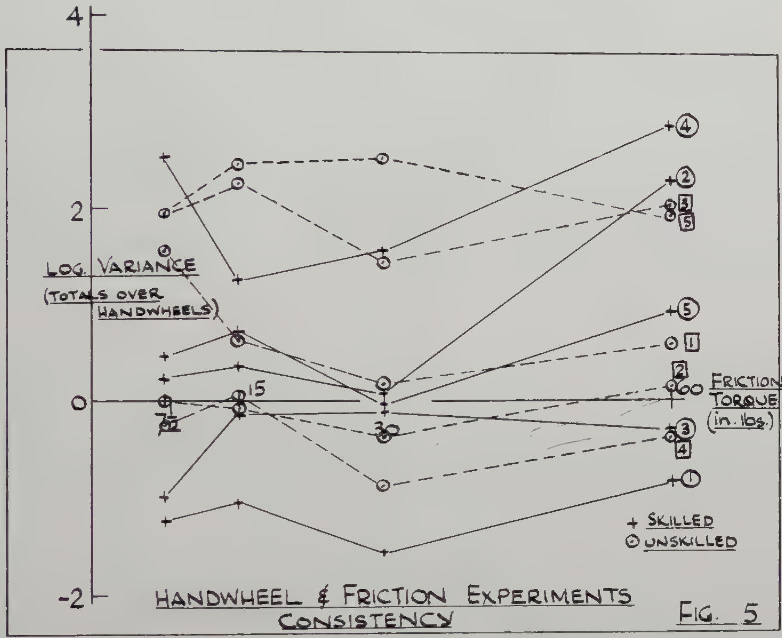
The results of the experiments concerning Handwheel Diameter and Spindle Friction Torque are summarized in Figs. 5 and 6 and Table 2. Friction appears as a significant factor, for the skilled operators. However, the graph does not show any clear trends in the effects of friction on individual operators and suggests, further, that the high significance for the skilled in relation to the lack of significance for the unskilled shown in Table 2 under ‘ consistency ’ is not such a valid result as the initial significance tests appear to indicate. The differences in performance related to friction as shown by Fig. 5 would appear fairly comparable between the two groups of subjects. Individual subjects again obviously differed greatly, but the absence of direct effect for the handwheels would appear to be contrary to what is commonly accepted and at least a Handwheels × Frictions interaction would have been confidently expected. The complete lack of Handwheel effect for consistency and the

Table 2. Analysis of variance. Effects of handwheel size and friction. Condition (*b*)

	Skilled subjects						
	Consistency				Time		
	Degrees of freedom	Mean square	Variance Ratio	Significance	Mean square	Variance Ratio	Significance
Handwheels	4	0·0196	0·7		0·0053	1·37	
Frictions	3	0·1906	6·75	0·1%	0·0254	6·56	0·1%
Subjects	4	1·1602	41·2	0·1%	0·1865	48·19	0·1%
H × F	12	0·0136	0·48		0·00443	1·144	
F × S	12	0·0574	2·03		0·00248	0·64	
H × S	16	0·0397	1·4		0·00914	2·362	2·5%
Residual	48	0·0282			0·00387		

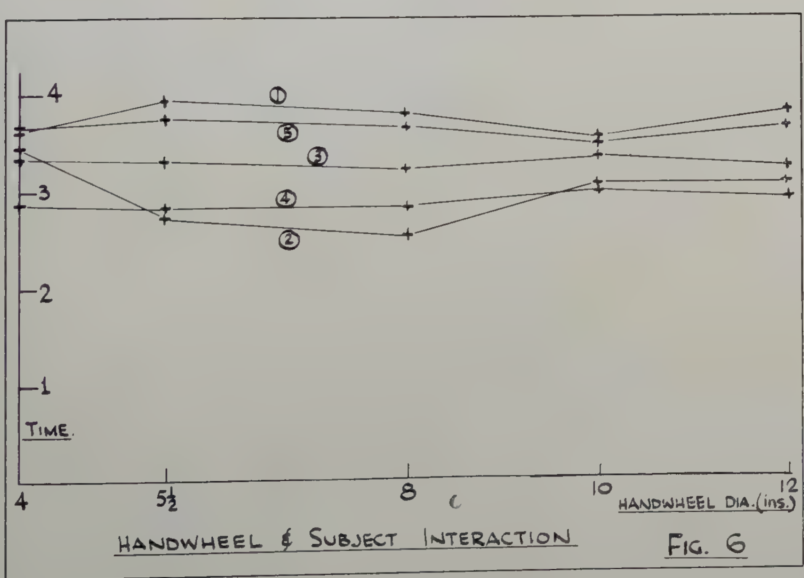
	Unskilled subjects						
	Consistency				Time		
	Degrees of freedom	Mean square	Variance Ratio	Significance	Mean square	Variance Ratio	Significance
Handwheels	4	0·0153	0·53		0·0091	1·921	
Frictions	3	0·051	1·78		0·0206	4·348	1·0%
Subjects	4	1·0732	38	0·1%	0·1519	32·06	0·1%
H × F	12	0·0346	1·2		0·0069	1·46	
F × S	12	0·0241	0·85		0·0042	0·90	
H × S	16	0·0215	0·75		0·0046	0·98	
Residual	48	0·0286			0·0047		

very low values for times shown in Fig. 6 can only cause speculation in view of the wide range of friction torques imposed and the ineffective levers provided to overcome them at some levels. The skilled subjects may have been affected by handwheel size, however, although the trend of the Handwheels × Subjects interaction is difficult to determine from an inspection of Fig. 6, and the effect at such a low significance could be a chance result.



HANDWHEEL & FRICTION EXPERIMENTS CONSISTENCY

FIG. 5



HANDWHEEL & SUBJECT INTERACTION

FIG. 6

This work has been carried out with the guidance and encouragement of Professor N. A. Dudley, Head of the Department of Engineering Production, University of Birmingham. Grateful acknowledgement is also required for the valuable assistance of Dr. G. Gregory, now of the University of Melbourne, and Dr. F. Benson, of the University of Birmingham, who gave guidance on the statistical aspects of the work ; J. T. Hawes, now at the Birmingham College of Advanced Technology, whose development of the apparatus was of great value ; P. V. Bertrand of the University of Birmingham who assisted with some of the tests and checked the calculations ; Messrs. Alfred Herbert Limited, Coventry, who provided the handwheels, and the many subjects who gave their time to produce these results.

Dans cet article, on décrit des expériences dont le but était d'étudier au point de vue précision et rapidité l'ajustement, au moyen d'un volant-manivelle, d'un cadran sur une aiguille : cette opération est similaire à celle qui est exigée sur beaucoup de machines-outils. Il y a une nette augmentation de la précision, lorsque, au lieu d'un cadran de 2 inches (5 cm), on utilise un cadran de 8 inches (20 cm), constatation qui justifie l'établissement d'une relation utilisable à des fins pratiques. La variation du diamètre de la roue-manivelle entre 4 (10 cm) et 12 inches (30 cm), ainsi que la variation du couple de freinage entre 7·5 et 60 lb. in (7 à 67 kg.cm) ont des effets négligeables.

Es wird über Experimente berichtet, in denen Wirkungen auf die Genauigkeit und Geschwindigkeit beim Einstellen eines Ziffernblattes auf einen Zeiger mit Hilfe eines Handrades untersucht wurden. Eine deutliche Erhöhung der Genauigkeit trat ein, wenn der Durchmesser des Ziffernblattes von 5 auf 20 cm vergrössert wurde. Sie war genügend beständig, um als praktische Forderung formuliert zu werden. Aenderungen des Handrad-Durchmessers zwischen 10 und 30 cm und des Reibungs-Moments zwischen 0,086 und 0,69 mkg waren zu vernachlässigen.

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AN AIR-VENTILATED SUIT FOR WEAR IN VERY HOT ENVIRONMENTS

By G. W. Crockford, R. F. Hellon, P. W. Humphreys and A. R. Lind
From the Medical Research Council's Unit for Research on Climate and Working Efficiency, Department of Human Anatomy, Oxford

Fifteen men, wearing an air-ventilated clothing assembly, were exposed to an ambient temperature of about 81°c (178°F). The suit was ventilated with dry air (6–7 mm Hg) at volumes between 283–707 l./min (10–25 c.f.m.) at temperatures between 30°c (86°F) and 37·8°c (100°F). At ventilating volumes of 424 l./min (15 c.f.m.) and over, the subjects were able to establish bodily thermal equilibrium in an hour, irrespective of the temperature of the air delivered to the suit. Thermal equilibrium was never achieved when only 283 l./min (10 c.f.m.) were supplied. In the interests of safety, it is recommended that such a suit in use ought to be supplied with dry air at a volume of not less than 707 l./min (25 c.f.m.) at a temperature of not more than 30°c (86°F).

§ 1. Introduction

Very high ambient temperatures may be found in certain locations in industry or in the armed forces, usually in relatively small, enclosed spaces where, for one reason or another, there is inadequate ventilation. The air temperatures within such spaces depend primarily upon the amount of heat generated by machinery or by some industrial process, and may reach values as high as 120°c (240°F), not infrequently with an additional radiant heat load. Even at low humidities, climates such as this are so severe that men cannot be expected to work in them for more than a short time without running the risk of heat collapse, and the severity of the conditions increases progressively if the humidity increases. Individuals who have to work in such environments for any length of time must therefore be provided with some form of protection against the high thermal load. One convenient method of protecting these men is to provide a ventilated clothing assembly.

The effectiveness of ventilated suit assemblies suitable for specific purposes has been examined in this country (Billingham and Phizackerly, 1957) and in the U.S.A. (Webb, 1956) for seated men flying aircraft ; the present experiments were designed to test a ventilated suit assembly suitable for use in the Royal Navy, for working men. A suit of this type might also be of value in many industrial situations.

§ 2. Methods and Equipment

2.1. *The ventilated suit assembly*

The ventilated suit assembly, which was supplied by the Admiralty, comprised two special garments : (*a*) an undergarment, made of a double layer of plastic film, the two layers separated by a loose plastic ' space filler '. The purpose of this garment was to distribute the ventilating air over a large area of skin, and the garment covered the trunk and legs ; (*b*) an outer garment made of impermeable but pliable plastic material, with an attached cylindrical helmet made of a double layer of clear plastic with an intervening air-space. A quilted layer of foam-plastic 5 mm thick, to act as an insulating barrier to

heat, was contained in the outer garment. Long string pants were worn beneath the ventilating undergarment to ensure a proper distribution of air over the legs by preventing the garment from ballooning on to the skin when air was supplied to the assembly. The looser fit of the undergarment over the trunk avoided the danger of ballooning on to the skin so that it was not necessary to wear a string vest.

The design of the assemblies was such that only a proportion of the ventilating air was delivered through a hose to the space between the two layers of plastic film comprising the undergarment (Fig. 1). This air then passed

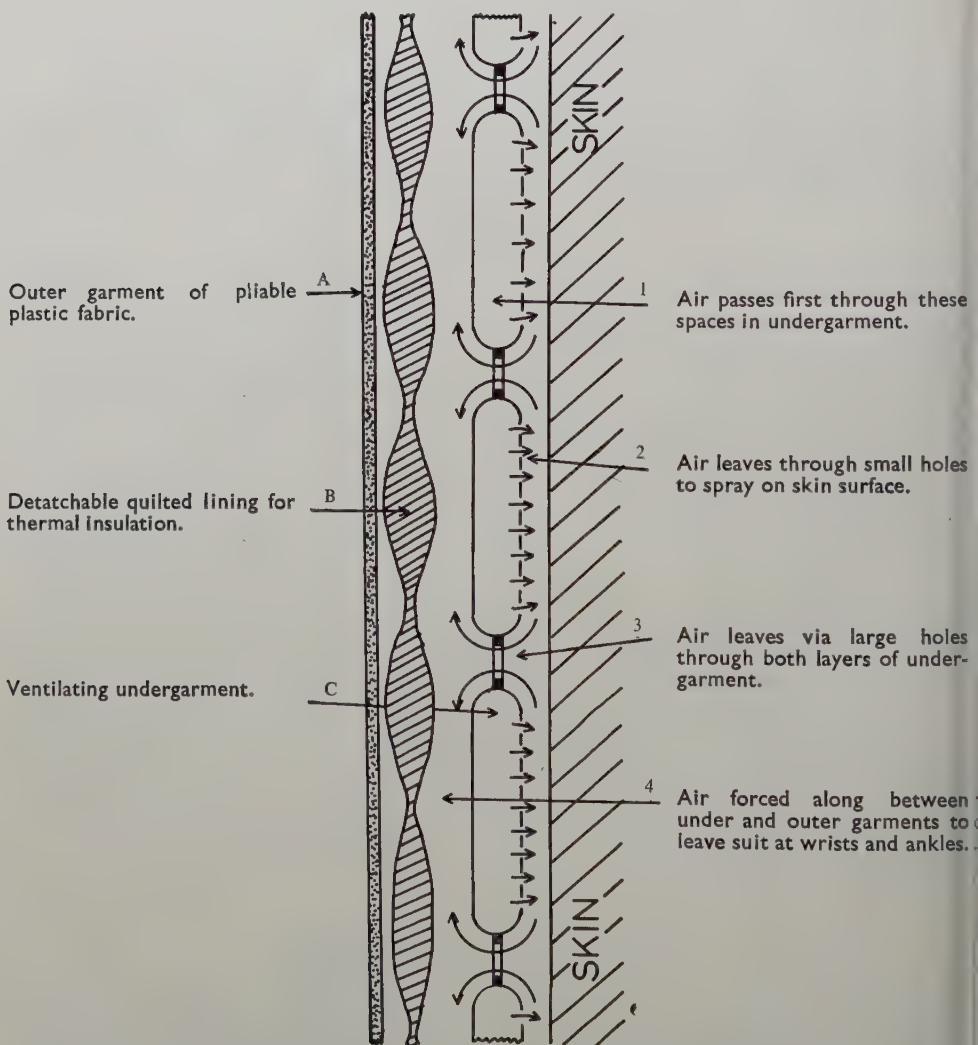

Figure 1. Diagrammatic, cross-sectional representation of the ventilated-suit assembly.

through numerous small holes in the inner layer of the undergarment to ventilate the skin. The air subsequently escaped outwards from the skin through holes of about 1 cm diameter through both layers of the undergarment, to the space

between the undergarment and the outer garment, finally exhausting from the assembly at the loose fitting wrists and ankles, and through a hole in the top of the helmet. The remainder of the ventilating air supplied to the assembly was led through a separate tube to a spray system inside the helmet.

2.2. *The air supply to the suits*

Air for ventilating the assembly was supplied from a compressor at a constant absolute humidity of 6–7 mm Hg, and was led through a rotameter before entering cooling or heating coils. The volume of air supplied was varied between 283 and 707 l./min (10–25 c.f.m.) and the temperature of the air was controlled, to ±0·5°C (0·9°F), between 30–37·8°C (86–100°F) as it entered the assembly.

2.3. *Subjects and conditions of exposure*

Twelve volunteer naval ratings and three of the observers acted as subjects ; their ages ranged from 22 to 42 years. Six of the subjects habitually took part in competitive games and sports. None had had any exposure to heat within the previous six months. Each subject was exposed only once to hot conditions to eliminate the effects of acclimatisation to heat.

The air temperature of the hot chamber in which subjects wore the ventilated suit assembly was between 78°C and 82°C (173°F–180°F). The humidity of the air was kept low, to allow the frequent entry of observers who had to take measurements. The air movement was between 0·5–0·8 m/sec (100–150 ft/min).

It was intended that each exposure should last for one hour. During the first 55 minutes the subjects stood in the hot room, and for the last 5 minutes they 'marked time' at an estimated energy cost of 120–150 kcal/m²/hr. In one trial, the subject was exposed for two consecutive hours, each of which was similar to the one described above.

Physiological observations in the hot chamber were confined to the recording of oral temperature (by 30 SWG copper-constantan thermocouple) and the counting of pulse rate every 5 minutes. It was not possible to make other measurements due to the hampering nature of the protective clothing. In addition, each subject was weighed, nude, just before entering the experimental chamber, and again when the clothing was removed as soon as the exposure ended. The temperature of the ventilating air as it entered the suit was measured every 5 minutes by thermocouple, and the air temperature in the chamber was read from an Assmann psychrometer.

The temperature of the ventilating air was 30°C (86°F), 32·2°C (90°F), 35°C (95°F) or 37·8°C (100°F), and the volume of air supplied to the suit was 283, 424, 566 or 707 l./min (10, 15, 20 or 25 c.f.m.). Table 1 shows the combinations of air temperature and air volume supplied to the suit during the fifteen experiments.

§ 3. Results

3.1. *Exposures of one hour's duration*

The oral temperatures and the pulse rates throughout the fifteen experiments are shown in Figs. 2 and 3. It is clear from these results that when the total ventilating volume was 283 l./min (10 c.f.m.), only one of the subjects

reached, or nearly reached thermal equilibrium, irrespective of the temperature of the air supplied. When the ventilating volumes were 424 l./min (15 c.f.m.) or more, every subject examined achieved, or nearly achieved thermal equilibrium as judged by their oral temperatures and pulse rates during the last 10–15 min of standing, irrespective of the temperature of the ventilating air.

Table 1. The combinations of ventilating air temperature and ventilating air volumes which were used during the fifteen tests. The experimental numbers do not refer to the order in which the experiments were performed

		Temperature of the ventilating air			
		86°F (30°C)	90°F (32·2°C)	95°F (35°C)	100°F (37·8°C)
Volume of the ventilating air	10 c.f.m.	Exp. 1	Exp. 2 Exp. 3	Exp. 4	Exp. 5 Ended after 36 min
	15 c.f.m.		Exp. 6	Exp. 7	Exp. 8
	20 c.f.m.		Exp. 9 Exp. 10		
	25 c.f.m.	Exp. 11 Exp. 12 Lasted for 120 minutes		Exp. 13 Exp. 14	Exp. 15

Table 2. The sweat losses per subject in litres for the fifteen combinations of ventilating air temperature and ventilating air volume

		Sweat losses (litres) per subject when the temperature of ventilating air was :			
		86°F (30°C)	90°F (32·2°C)	95°F (35°C)	100°F (37·8°C)
Volume of the ventilating air	10 c.f.m.	0·580	0·835	0·470	0·250 (36 min)
	15 c.f.m.		0·575	0·635	0·480
	20 c.f.m.		0·475 0·605		
	25 c.f.m.	0·345 0·525			0·355

If these conclusions are accepted, the results suggest that at a total ventilating volume of 424 l./min (15 c.f.m.) all the sweat needed for thermo-regulation was evaporated, so that the provision of greater quantities of air did not serve any useful purpose from the viewpoint of evaporation of sweat. Increase in the ventilation volumes at the lower air temperatures could be expected to

increase the subject's heat loss by forced convection, but this effect would not be large since the difference between skin and air temperatures must have been small. In fact changes of this sort were obscured by the large individual

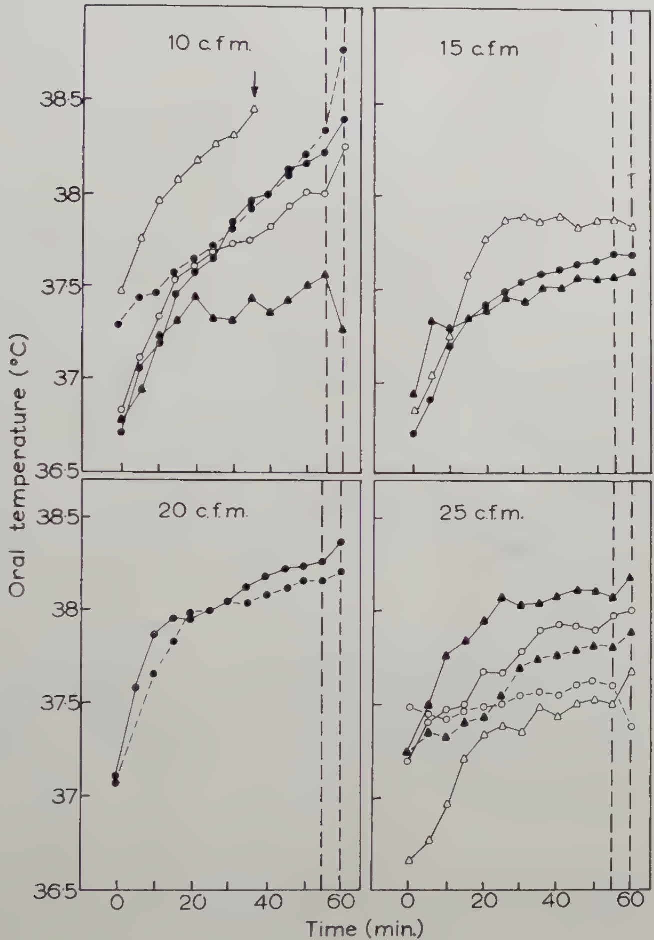

Figure 2. The individual oral temperatures during the experiments when different ventilation rates were supplied at 30°c (O), 32·2°c (●), 35°c (▲) and 37·8°c (Δ). The arrow indicates the point at which one subject was withdrawn from the chamber, and the vertical dotted lines show when work periods commenced.

variation, and by the diurnal variations introduced by performing some experiments in the morning and some in the afternoon. Because of these variations, the sweat losses, shown in Table 2, show only that the temperature and the volume of ventilating air did not have a marked effect on the rate of sweating which was, on the average, just under half a litre per hour.

3.2. *Exposure of two hours' duration*

The oral temperature and pulse rate of the one subject who completed a two-hour exposure are given in Fig. 4. Air at a temperature of 30°c (86°F) was supplied to him at a rate of 707 l./min (25 c.f.m.), and it is clear that he

maintained his bodily thermal equilibrium during the test. His sweat loss or the two hours was 1·01 litres.

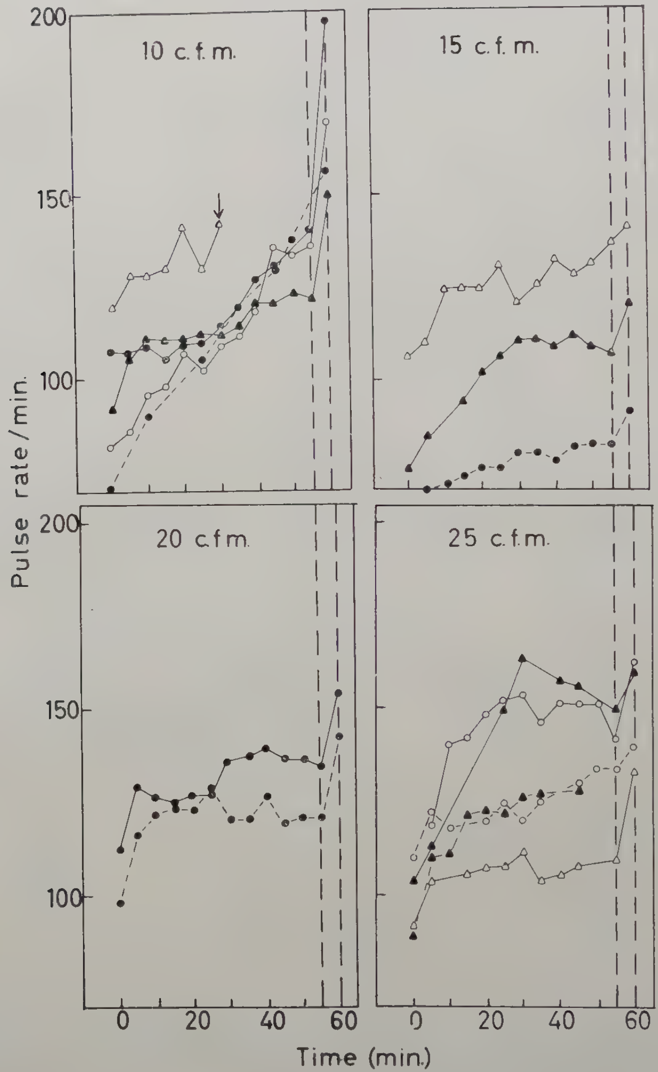

Figure 3. The individual pulse rates during the experiments when different ventilation rates were supplied at 30°c (O), 32·2c (●), 35°c (▲) and 37·8°c (Δ). The arrow indicates the point at which one subject was withdrawn from the chamber, and the vertical dotted lines show when work periods commenced.

3.3. *Exposure of less than one hour's duration*

One subject failed to tolerate the exposure conditions for one hour. This experiment lasted for 36 minutes, when the subject was withdrawn from the chamber. The volume and temperature of the ventilating air were 283 l./min (10 c.f.m.) and 37·8°c (100°F) respectively. This subject had a high initial pulse rate and oral temperature. After 36 minutes the subject complained of dizziness and was withdrawn from the chamber. He subsequently made a

quick recovery. It is considered that this subject suffered from an incipient heat collapse which was presumably hastened by his high initial oral temperature and pulse rate.

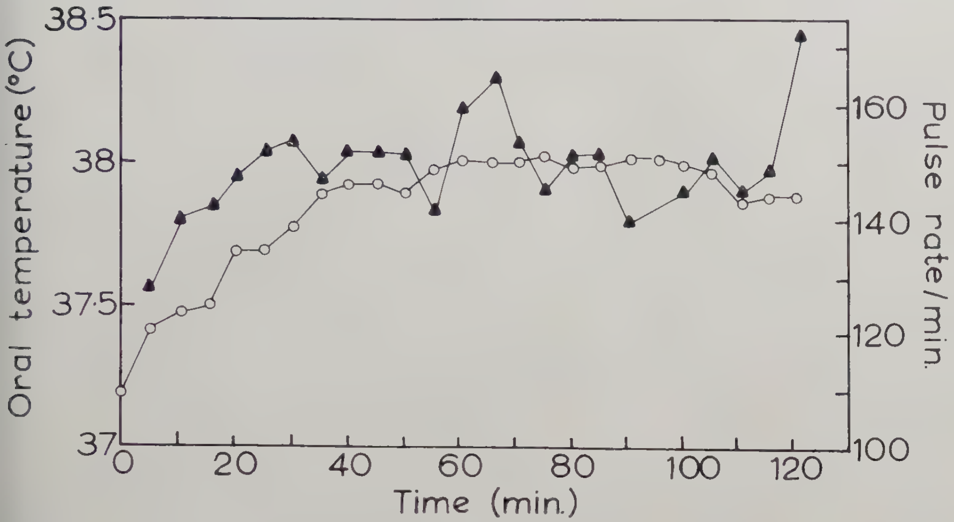

Figure 4. The oral temperature (O) and pulse rate (▲) of a subject who was exposed for two hours in the hot room while the suit was ventilated at 25 c.f.m. with air at a temperature of 30°C (absolute humidity 6–7 mm Hg). The subject worked at 55–60 min and at 115–120 min.

3.4. *Exposure without ventilation*

The conditions under which it is intended to use the suit are such that it may be necessary to wear it for a short time with no ventilation. It was therefore decided to examine the effects of wearing the suit, unventilated, for two periods of 10 min ; the first 10 min to be spent in the cool surroundings outside the hot-room and the second 10 min to be spent inside the hot-room after a brief recovery period. During the first period the oral temperature was not recorded, but air samples were taken from inside the helmet in order to measure the concentration of the carbon dioxide. During the second 10-min period the subject's oral temperature was measured but no air samples were taken.

In Fig. 5 the concentration of oxygen and carbon dioxide are given for the 10-min period spent in the cool air. The carbon dioxide concentration rose rapidly within 5 min to about 5 per cent while the oxygen fell rapidly to about 14 per cent in the same time. No significant change in these values occurred thereafter. Presumably the movements of the subject in the suit resulted in a ' bellows ' effect, leading to the establishment of this equilibrium.

After a brief respite the subject entered the hot-room (81°C ; 178°F) and his oral temperature for the next 10 min is given in Fig. 6. The oral temperature rose steeply by 1·2°C (2·2°F) during the 10 minutes.

The impressions of the subject were that the accumulation of carbon dioxide was the limiting factor rather than the heat. The results suggest that this may not be so, particularly for the wearer of the suit who had just completed a period of work in hot surroundings because he would undoubtedly

then have a higher initial temperature than the subject in the test. In such instances deep body temperatures might reach levels high enough to induce heat collapse.

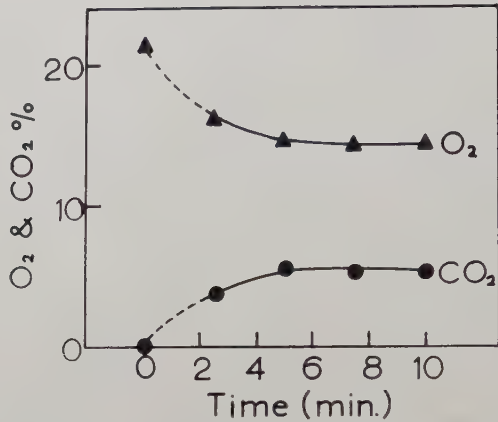

Figure 5. Changes in O_2 and CO_2 concentration in the helmet of a non-ventilated suit.

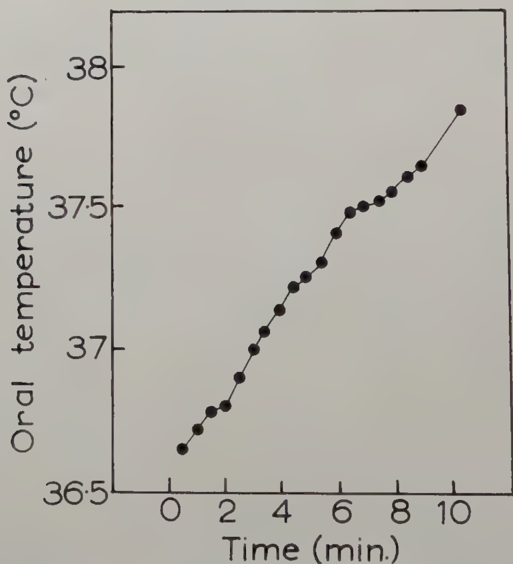

Figure 6. Oral temperature of a subject who was exposed to the hot conditions in a non-ventilated suit.

3.5. *Relative volumes of air supplied to undergarment and helmet*

Tests were carried out to determine the relative proportions of air supplied to the undergarment and to the helmet for various flow rates, and to determine the total head of pressure of the air at the point of entry to the suit. The results are given in Table 3. Three rotameters were used and the degree of accuracy to which these can be read accounts for the slight discrepancy between the figure for total flow rate and the figure obtained from adding the two partial flow rates.

It is seen from Table 3 that in every instance approximately half the air goes to the helmet.

Table 3. Relative volumes of air supplied to the undergarment and to the helmet

Total air supply c.f.m.	Supply to helmet c.f.m.	Supply to undergarment c.f.m.	Total head of pressure cm H_2O
10	4·8	5·1	8·9
15	7·1	8·0	15·7
20	9·0	11·6	29·0
25	12·4	14·8	45·0

§ 4. Conclusions

When fifteen subjects, wearing a ventilated suit assembly, were exposed to an air temperature of 80°C (178°F), thirteen successfully completed one hour's exposure and one completed two hours' exposure without ill effects. The other subject was withdrawn from the chamber after 36 min when he was considered to be in a state of incipient heat collapse ; the air supplied to his suit assembly was 283 l./min (10 c.f.m.) at 37·8°C (100°F), i.e. the least beneficial of all the combinations of air temperature and volume of air supplied.

Variation of the temperature of the air supplied to the suit had no demonstrable effect on these experiments, but a critical total volume of air supplied appeared to be reached between 283 and 424 l./min (10–15 c.f.m.), since only at the lowest volume of air supplied did the subjects fail to achieve, or nearly achieve bodily thermal equilibrium. When 707 l./min (25 c.f.m.) of air was supplied to the suit at 30°C (86°F), one subject satisfactorily maintained thermal equilibrium for two hours.

If such a suit is used to prevent men who have to work in high ambient temperatures, it is recommended that it should be ventilated with dry air (6–7 mm Hg absolute humidity) at a temperature not exceeding 30°C (86°F) at the point where it enters the suit, and at a rate not less than 707 l./min (25 c.f.m.), in order to provide an adequate safety factor.

Acknowledgements The authors are indebted to their Lordships of the Admiralty for permission to submit this paper for publication ; also to Dr. D. McK. Kerslake and to Mr. D. F. Brebner of the Institute of Aviation Medicine, Farnborough, for the hot-room and technical facilities ; to the naval volunteers from H.M.S. *Sultan* who so willingly acted as subjects and for whose attendance we are indebted to the Commanding Officer, and to Messrs. K. Sweetland and B. Purvis for technical assistance. Our thanks are due to Mr. F. E. Smith for invaluable administrative arrangements; and to Mr. C. R. Underwood for kindly undertaking the air flow and air pressure measurements.

Quinze sujets masculins portant un ensemble vestimentaire ventilé par air ont été exposés à une température ambiante d'environ 80 °c. Le vêtement était ventilé par de l'air sec (pression de vapeur d'eau : 6 à 7 mm Hg), d'un débit variant entre 283 et 707 l/min et à des températures situées entre 30 °c et 37,8 °c.

Pour des débits égaux ou supérieurs à 424 l/min, les sujets étaient en mesure d'atteindre un équilibre de leur température corporelle en l'espace d'une heure, quelle que soit la température de l'air ventilant le vêtement. Par contre, l'équilibre thermique de l'organisme n'était jamais réalisé lorsque la ventilation n'était que de 283 l/min. Pour assurer une marge de sécurité, il est recommandé, lors de l'emploi d'un tel vêtement, d'utiliser de l'air sec, à un débit supérieur à 707 l/min et à une température ne dépassant pas 30 °c.

Fünfzehn Versuchspersonen, je einen mit Luftzufuhr versehenen Kühlanzug tragend, wurden einer Umgebungstemperatur von 81°c ausgesetzt. Die Kühlanzüge wurden mit trockener Kühlluft (6–7 mm Hg) gespeist deren Temperaturen zwischen 30°c und 37·8°c lagen ; zwischen 283 und 717 Lr./Min Külluft wurde den Anzügen zugeführt. Wenn die Luftzufuhr 424 Lr./Min betrug oder diesen Wert überschritt, konnten die Versuchspersonen innerhalb einer Stunde bei allen Versuchstemperaturen der Kühlluft ein körperliches thermisches Gleichgewicht herstellen. Wenn die Luftzufuhr hingegen nur 283 Lr./Min betrug, wurde in keinem Versuch ein thermisches Gleichgewicht hergestellt. Aus Sicherheitsgründen empfehlen die Verfasser, dass luftgespeisten Kühlanzügen, wenn im Gebrauch, nicht weniger als 707 Lr./Min Trockenluft zugeführt werde, deren Temperatur 30°c nicht übersteigen soll.

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WAR OFFICE
CLOTHING AND EQUIPMENT PHYSIOLOGICAL RESEARCH ESTABLISHMENT

By E. T. Renbourn and H. C. W. Stockbridge
C.E.P.R.E., ℅ Royal Aircraft Establishment, Farnborough, Hants

The history of the Establishment, and the nature of the researches undertaken is briefly reviewed. An account of past work follows and describes problems of the soldier's load, his working environment, his clothing and protective equipment and the design of the fighting vehicles or guided weapon systems he may have to operate.

§ 1. History of the Establishment

Military Ergonomics in the Ministry of Supply began in 1948 with the setting up of the nucleus of a team, known as the Clothing and Equipment Physiological Research Establishment (C.E.P.R.E.), whose purpose was to study the human aspects of military ' hardware '—the clothing, equipment, vehicles, armaments, communication systems, etc.—intended for the use of land forces in all theatres of war. Sections of the Establishment dealing with Applied Physiology, Experimental Psychology and Applied Textile Technology were set up around a ' core ' of Statisticians and Biophysicists. Added to these was a small section of Army officers in control of the troops attached to the Establishment and acting as military advisers. The main function of the Military Section is, however, to assess the serviceability and wear-and-tear life of clothing and various types of equipment. This is done in the form of normal and accelerated trials, the latter being carried out on a specially designed combat course including a ' rain shed ' where rainfall can be simulated.

§ 2. Nature of the Research

Close collaboration is maintained with service laboratories concerned with ergonomic problems, with the Army Operational Research Group of the War Office, the laboratories of the Medical Research Council and various Universities, and with industrial organizations concerned with research and development.

C.E.P.R.E. has the responsibility of helping Design and Development authorities in the War Office to produce items required to meet ' Military Characteristics ', i.e. the specifications laid down by the Services. After accepting an item the War Office carries out extensive trials to cover operational aspects which cannot be considered during the relatively small and short trials done by the Ministry.

Problems are, in general, tackled from three levels of integration which, when possible, are carried out in orderly sequence. Thus we have (1) what may be called the ' bench level '—in physiological experiments, the simulation of the body or its parts, the clothing, equipment, vehicles, etc., in a physical model, and in psychological experiments, attempts to isolate certain features of performance for study apart from their relation to any particular equipment ; (2) the ' laboratory level '—with groups of service men using mock-up equipment or working in an artificial climate, and (3) the ' operation level ' in the field under appropriate climatic conditions. The first two ' levels ' are of

screening value, but the last is regarded as the most valid, for only in the field can the broad ecological aspects be approached and the morale and motivation factors in any way reproduced.

Physiological problems in C.E.P.R.E. are concerned with (*a*) comfort, protection and efficiency of the soldier, in all climates, wearing his clothing and using his personal equipment ; (*b*) problems of air and radiant temperature ; ventilation and toxic fumes ; vision and hearing ; seating, posture, work space, noise, vibration and blast, etc., in fighting vehicles, control vans and tents, and (*c*) problems of load carriage, whether of the soldier's accoutrements, man-pack carriers, stretchers or man-handling operations.

Psychological problems are usually of an applied experimental nature and concerned with the design of equipment such as a tank or a radar system.

§ 3. Review of Past Work

3.1. *Problems of the Soldier's Load*

The laboratory treadmill has been found of great value in problems of walking. Using electromyography and high speed cinematography, a study showed the presence of little known movements of the nude foot (Hardy 1954, unpublished M.O.S. Report). Another piece of work carried out on the treadmill, demonstrated that the addition of one pound on the foot is equivalent to about two pounds carried on the back (Draper *et al.* 1953). The effect of the soldier's load is assessed not only subjectively but also by changes in body temperature, pulse rate and energy metabolism during operational activities out of doors (Reid *et al.* 1955). In a given group of men (on similar activities) the respiratory ventilation volume, measured with the Integrating Motor Pneumotachograph or I.M.P., has been found a sufficiently good comparative measure of energy expenditure, but the pulse rate is a simpler and more sensitive measure of the physiological and psychological strain of military loads (Reid *et al.* 1955).

It has for long been widely accepted that when a marching soldier carries more than, say, one-third of his body weight, he soon loses physiological efficiency as measured by pulse rate or metabolic cost. Exactitudes in load carriage are unrealistic, for the soldier's loaded web equipment has a fixed content ; but soldiers are individuals in weight, training and muscular development. Packs are standardized in size, so that what lies well on the back of a six-foot man may be over the buttocks of his shorter companion. Work at C.E.P.R.E. suggests that the type of equipment best for marching is not necessarily the best for continuous activity (Reid *et al.* 1955). There is at present a move to have the whole load carried around the waist and hips, as was done in the British ' Valise Equipment ' of 1879 (Renbourn 1954), but this necessitates a tight belt, and the man with a small waist may find it difficult to find space for the pack, pouches and accessories. Work in C.E.P.R.E. has shown that when loads are carried in this way, men still prefer some ' tension ' on the shoulders but this may be of psychological rather than physiological significance.

Physiological strain gives little indication of a man's efficiency as a soldier. For this reason performance tests such as rifle fire, digging, loading and unloading magazines are normally included in load carriage trials (Reid *et al.* 1955).

3.2. *Working Environment*

The concept of 'Corrected Effective Temperature', although perhaps the best of such scales for assessing the stress of indoor environments, is still open to a number of disadvantages and does not lend itself for use in small enclosed spaces, as, for instance, in a tank. Similarly the overall ventilation rate may have little meaning under such conditions, for the interest is in the immediate working environment of the man. Since the intake of carbon monoxide into the lungs depends on the man's activity, blood sampling (before and after exposure), as well as analysis of the air inspired, is necessary to assess the effect on the man. Trials have shown the Scholander and Roughton method using finger prick blood to be the most suitable for field work (Stokes and Yeo, 1958 unpublished M.O.S. Report).

Body temperature measurements of the surface (skin) or body interior (mouth or rectum) are frequently used in problems of muscular work, the working environment or the soldier's clothing, but there are a number of practical considerations to be taken into account. Surface temperatures are, of necessity, taken over hairs, and covering a thermocouple with an impermeable layer may modify the underlying temperature. It may be wise to assume that surface temperature is but a 'near skin' measurement and hence cannot have a high order of accuracy. The conventional 'mean skin temperature' or 'm.s.t.' is derived from a variable number of arbitrary sites whose readings are weighted for 'area' (Tolson 1956, unpublished M.O.S. report). Under conditions of warmth, temperature differences between sites is minimal and the 'm.s.t.' is meaningful and a qualitative measure of subjective thermal comfort. Under the severe heat stress of working in an impermeable garment the 'm.s.t.' is the most sensitive measurement to be taken (Draper *et al.* 1955). With exposure to cold, the skin (and blood) of the limbs, especially their tips, cools much more rapidly than that of the head or trunk. It is not usual to include the toe or finger in the normal use of the 'm.s.t.', and where a single reading is taken from the foot or hand, neither the area weighting nor the 'm.s.t.' take into account the functional importance of local cold discomfort or frostbite. With a clinical thermometer the rectal reading will stabilize in about $2\frac{1}{2}$ min, and in the mouth, under warm conditions, within $2\frac{1}{2}$ to 5 min. However, when the environmental temperature is about 55°F or less, the oral equilibration time is considerably longer, and at 40°F or less, errors of about 1–2°F may occur. By the use of thermocouples with the mouth continuously closed, it can be shown that the oral temperature follows the rectal temperature fairly faithfully under most physiological conditions, but the curves may sometimes cross for no obvious reason. It is generally assumed that in the absence of drinks, etc., the oral temperature is below the rectal temperature, but this is by no means invariably true even under resting conditions (Renbourn and Taylor 1956, unpublished M.O.S. report).

The rectal temperature is generally accepted as more or less identical with the so-called internal or core temperature, but most observers have found it to be about 1°F higher than blood temperature. In spite of the above findings it may be accepted that under controlled conditions on a group of individuals, differences in skin, oral and rectal temperature are of value in routine work.

In climatic chamber and field work the physicists in the Establishment are responsible for the simple meteorological measurements. Data for experiments done in the climatic chamber strongly suggests that the so-called ‘ damp cold ’ phenomenon of a temperate winter—the feeling of ‘ penetrating chill ’ out of doors when the temperature is near freezing point and humidity high—is, apparently, not due to the humidity of the air itself but to cold rooms and to other climatic factors, viz. absence of sun or the presence of wind (Renbourn *et al.* 1959).

Trials carried out under desert conditions confirmed the high solar heat load on the soldier, but demonstrated that ultra-violet reflectivity of sand is relatively low and ‘ glare ’ not important from the terrain itself (Taylor 1955, unpublished M.O.S. report). Except where night vision is important, the intensity of the tint of a pair of goggle lenses is not very critical for visual acuity in the desert, and the ordinary motorised infantry man does not require sun glasses (Reid *et al.* 1955). So far as the driver is concerned, the glare can be controlled by painting a green strip 2 in. wide across the top of the windscreen sufficient to eliminate the sky when driving on level ground (Dwyer 1947). Alternatively he should wear suitable goggles.

There are now sufficient data to warrant the assumption that in the tropics (and to some extent in a European summer) the normal resting body temperature is raised in many individuals by $\frac{1}{2}$–2°F (Renbourn, *in press*). Current work in this laboratory has shown that, under controlled conditions, prolonged emotional stress (as for example in a man waiting for an athletic contest, to box an unknown opponent or before entering a plane prior to a parachute drop) may itself, in some individuals, produce a rise of body temperature without affecting the pulse rate. The above facts may, possibly, be related to the experience that poor morale and anxiety seem to impair acclimatization and adaptation in the tropics and to prepare the way for disorders such as heat exhaustion and heat stroke (Renbourn, *in press*). There is now some confirmation for the belief that extra salt—apart from that normally taken in the food—may not be required for the soldier's health in the jungle or desert (Renbourn *in press* ; Ladell 1957), but this may not apply to the heavy worker in hot industries or in hot mines. To the soldiers more salt means more thirst, and is hence a drain on his water bottle. Extra salt is probably no guarantee against heat disorders, and may produce nausea in some men and aggravate prickly heat in others.

3.3 *Clothing and Protective Equipment of the Soldier*

The various natural textile fibres such as wool, silk, linen and cotton, and synthetic ones such as nylon and Terylene vary widely in chemical nature, but this is neutral as far as the body is concerned. Chemical properties, however, play an important part in the resistance to flame and radiant heat flash. Physical properties of a fibre may be appreciably modified by the geometry of the weave. The important physiological characteristics of a cloth are : (1) water absorption, (2) air and wind permeability, and (3) thermal insulation. Under practical conditions these properties cannot be separated. The warmth of a cloth is in great part due to the pockets of relatively still air in its interstices and in the boundary air layer on either face. Such air can be moved by

convection currents from the warm body, by currents arising from its movements and from wind. Absorption of water and water vapour into the fibres not only keeps the skin dry but is associated with the liberation of an appreciable quantity of heat. Such ' sorption ' heat (most marked with wool) is believed to prevent undue cooling of the body after exercise and sweating. On the other hand, water taken up into the pores of a fabric displaces air and hence decreases thermal insulation. Work in this laboratory has suggested that even under optimal conditions, wool in the form of three layers of clothing may show but little of the theoretical ' sorption ' heat (Renbourn *et al.* 1959).

Cold weather clothing is assessed at C.E.P.R.E. in comparative trials on groups of men under cold chamber and realistic field conditions. Measurements are taken of body temperature, sweat loss and sweat retention in garments together with suitable performance tests and subjective assessment. In such trials, the head, feet and hands must be carefully considered. The head is a potent source of heat loss in the cold (Froese and Burton 1957), a fact that the soldier must be taught to respect. Maintaining the warmth of the trunk prevents the limbs from cooling unduly. Similarly, although extra insulation of the wrist and the back of the hand is required to keep the fingers warm, it must be remembered that covering the fingers with insulation more than $\frac{1}{4}$ in. thick, increases cooling rather than adding warmth. Insulation also impairs dexterity.

Tropical clothing should absorb sweat, be loose, easily washable and dry quickly, while ventilation openings (cap, underarm, neck, etc.) must be large. In a hot climate, sweat retained at skin level may lead to discomfort and predispose to prickly heat and fungus infection (Renbourn, *in press*). The ' chimney ' ventilation of a loose bush jacket is impaired by the ever-present belt, which supports the trousers and acts as part of the web equipment. Although no objective proof of the value of a Brynje or ' string ' vest, for use in either cold or hot conditions, has been forthcoming, such garments add to subjective comfort under conditions of profuse sweating (Kenchington 1956), and may be a good ' spacer ' in the presence of radiant heat flash or when worn beneath impermeable garments.

It has for long been said that leather ' breathes '—presumably passes water vapour freely. Dense sole leather passes but little, and the amount getting through ' dubbined ' or polished uppers must be negligible. Work in C.E.P.R.E. shows that the virtue of leather lies in the fact that it is a good heat insulator and absorbs sweat or its vapour from the socks and skin. No obvious short-term physiological or clinical disadvantages of rubber or composition soles, or socks of loosely woven pure nylon or Terylene (which can be boiled and do not shrink) have yet been noted. A good military boot should have a protective sole, a rigid toe cap, a good support between heel and instep, and sufficient room in the forepart to allow joint movements. It has been shown that a removeable ' honeycomb ' insole keeps the feet warm in the cold and cooler under hot desert terrain (Stokes 1955, unpublished M.O.S. Report).

3.4. *Design of Fighting Vehicles and Guided Weapon Systems*

Many of the details of the applied experimental psychological work are classified as secret but it is still possible to describe in a general way some of the more important projects.

The driving and crew compartments of fighting vehicles have been studied in connection with the position of the controls, the design of the seats, and instruments, and the allotment of work space to the operator (Dennis 1959, unpublished M.O.S. Report). The effects of noise, heat and vibration as encountered in vehicles have been considered (Dennis, *in manuscript*, unpublished M.O.S. Report). For example vibration affects visual acuity and is dependent upon the effective amplitude at the head. This in turn is determined by the seat padding and bodily posture.

Work on guided weapon systems centres mainly round the design of consoles for air defence sites (Anderson and Corkindale 1955, unpublished M.O.S. Report) and advising on problems of aiming and tracking in ground-to-ground or ship-to-air systems. Studies of the target handling capacity of the human operator have been carried out and estimates of speed and accuracy using specific systems have been experimentally determined (Stone, Anderson and Henderson 1958, unpublished M.O.S. Report). Population stereotypes for coding by shape and colour of lamp order signals have been surveyed (Stone 1956, unpublished M.O.S. Report) and advice given on lighting, seating and letter legibility (Forrest and Anderson 1953, unpublished M.O.S. Report). Ease of maintenance (Henderson 1959, unpublished M.O.S. Report) is important as well as ease of operation, and the designer must have both in mind.

In command link systems where the operator personally guides the missile on to the target, the initial dispersion of the missile may require the operator to use unaided vision for gathering by one eye and aided vision for the remainder of the flight by the other. The time to operate systems of this type has received attention (Stockbridge *in press* and 1958, 1959, unpublished M.O.S. Reports).

Additional fields of work investigated include the effect on hearing thresholds and the location of sound in headgear (Holding and Dennis 1954, 1955, unpublished M.O.S. Reports), the application of information theory to such human operator problems (Draper 1944, 1956, unpublished M.O.S. Reports), and the representation of aircraft by pictorial signs (Provins *et al.* 1957).

Nous donnons ici un historique du C.E.P.R.E. et indiquons quel genre de recherches y sont faites en général. On trouvera un résumé de travaux faits par le passé ainsi qu'un tableau des différents problèmes auxquels nous avons eu à faire face : le paquetage du soldat, ses conditions de travail, son habillement, son equipement protecteur, le dessins des véhicules de combat ou des engins téléguidés dont il peut avoir a de servir.

Nach einem Überblick über die historische Entwicklung des Institutes und die Art der geleisteten Forschungsarbeiten werden Einzelheiten der bereits geleisteten Arbeit beschrieben. Es werden Fragen behandelt die sich mit der Traglast eines Soldaten, den Arbeitsbedingungen, der Kleidung und Schirtzausrustung sowie der Konstruktion von Kampffahrzengen oder Fernstenerwaffen befassen, die der Soldat gegebenenfalls Zu bedienen hat.

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An analysis of 195 reports and memoranda by subject matter shows that 29 per cent of internal ublications dealt with Clothing (General), 11 per cent with Footwear, 24 per cent Equipment General), 10 per cent Fighting Vehicles, 12 per cent Radar, 10 per cent Research (General), per cent Instrumentation while 2 per cent were Miscellaneous.

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CONFERENCE ON "ERGONOMICS IN IN INDUSTRY"

A CONFERENCE with this title was held under the auspices of the Department of Industrial and Scientific Research from 27 to 29 September 1960 at the Connaught Rooms, London. It arose following requests from the Trades Union Congress and the Ergonomics Research Society for a meeting to follow up a conference sponsored by the European Productivity Association which was held in Zurich during March 1959 under the title "Fitting the Job to the Worker" (see *Ergonomics*, **2**, 305–9).

One of the main purposes of the Zurich Conference was to stimulate meetings in E.P.A. member countries which would bring work in the field of ergonomics to the attention of higher industrial management. This the London Conference, which was attended by some 300 delegates from a wide range of industrial firms and other interested bodies, certainly achieved. The Information Division of D.S.I.R., and especially Miss H. M. Clay, on whom rested the chief responsibility for the arrangements, are to be congratulated on an important, valuable and well organized set of meetings.

A volume of Proceedings, including full texts of the papers delivered, a verbatim report of the discussions, and a brief description of the Conference Exhibition, will be published by Her Majesty's Stationery Office.

PROGRAMME

OFFICIAL WELCOME by **Sir Harry Jephcott,** *Chairman of the Council for Scientific and Industrial Research*

OPENING ADDRESS by **The Rt. Hon. Viscount Hailsham,** Q.C., *Lord President of the Council and Minister for Science*

1. WHAT ERGONOMICS MEANS

(a) **Implications of Physiological Research** by **O. G. Edholm,** *Head of Division of Human Physiology, National Institute for Medical Research, Medical Research Council.*

(b) **Implications of Psychological Research** by **A. T. Welford,** *Fellow of St. John's College, Cambridge; University Lecturer in Experimental Psychology.*

Chairman: **Sir Harold Himsworth, K.C.B., F.R.S.,** *Secretary of the Medical Research Council.*

2. THE PLACE OF ERGONOMICS IN INDUSTRY.

K. F. H. Murrell, *Research Fellow in Psychology, University of Bristol.*

L. G. Norman, *Chief Medical Officer, London Transport Executive.*

A. J. Mann, *until recently Director and General Manager of David Harcourt Ltd.*

S. A. Robinson, *General President of National Union of Boot and Shoe Operatives.*

Chairman: **L. T. Wright,** *General Secretary of the Amalgamated Weavers' Association.*

3. ERGONOMICS AND PRODUCTION.

(a) **Design of Instruments,** by **J. Spencer,** *Department of Psychology, University of Reading.*

(b) **New Ideas about Lighting,** by **R. G. Hopkinson,** *Head of Lighting Section, D.S.I.R. Building Research Station.*

(c) **Application in Machine Design,** by **W. T. Singleton,** *Lecturer in Ergonomics, College of Aeronautics, Cranfield; formerly Head of Ergonomics Department, British Boot, Shoe and Allied Trades Research Association.*

Chairman: **J. Drever,** *Professor of Psychology, University of Edinburgh.*

4. ERGONOMICS IN THE POST OFFICE.

K. S. Holmes, C.B.E., *Director of Postal Services, General Post Office.*

W. F. Floyd, *Head of the Department of Ergonomics and Cybernetics, Loughborough College of Technology.*

R. Conrad, *Assistant Director, M.R.C. Applied Psychology Research Unit.*

Chairman: **H. Briggs,** *Labour Adviser, Unilever Ltd.*

5. **ERGONOMICS IN THE STEEL INDUSTRY.**
S. Laner, *Human Factors Section, Operational Research Department, British Iron and Steel Research Association.*
E. R. F. W. Crossman, *Lecturer in Psychology, University of Reading.*
R. F. Hellon, *M.R.C. Unit for Research on Climate and Working Efficiency.*
Chairman: **C. G. Williams,** *Director and General Manager of Shell Research Ltd.*

6. **ERGONOMICS AND PRODUCTS.**
(a) **Functional Anthropometry,** by **J. S. Weiner,** *Reader in Physical Anthropology, University of Oxford; Hon. Asst. Director, M.R.C. Unit for Research on Climate and Working Efficiency.*
(b) **Ergonomics at Renault,** by **A. Y. Wisner,** *Head of Physiological Section, Department of Scientific Research, Regie Nationale des Usines Renault.*
(c) **Human Problems in Transport,** by **G. C. Drew,** *Professor of Psychology, University College, London.*
Chairman: **M. G. Bennett,** *Superintendent Operational Research, British Transport Commission.*

7. **THE FUTURE OF ERGONOMICS**
G. P. Wade, *Director of Department of Work Study and Staff Training, Engineering and Allied Employers' West of England Association.*
D. E. Broadbent, *Director, M.R.C. Applied Psychology Research Unit.*
J. C. Pritchard, O.B.E., *Director, Furniture Development Council.*
A. Graham, *Head of Performance Section, Central Work Study Department, Imperial Chemical Industries Ltd.*
S. H. Clarke, C.B.E., *Director, D.S.I.R. Warren Spring Laboratory.*
Chairman: **Sir Harry Melville, K.C.B., F.R.S.,** *Secretary of the Department of Scientific and Industrial Research.*

DEMONSTRATIONS

1. (a) **G.P.O. Research Stations.** Methods of recording muscular activity during lifting movements.
(b) **Institute of Aviation Medicine.** Effect of seat height on the operation of foot controls.

2. **British Boot, Shoe and Allied Trades Research Association.** Leather-cutting bench designed to minimise unnecessary movements; special lighting for this and similar operations; and variable-speed controls for industrial sewing machines.

3. **D.S.I.R. Building Research Station.**
(a) Factors affecting glare in lighting.
(b) Artificial lighting as a permanent supplement to daylight.

4. (a) **M.R.C. Climate and Working Efficiency Research Unit.** Air-ventilated protective clothing for use in very hot surroundings; and breathing sets for rescue work in mines.
(b) **M.R.C. Human Physiology Group of the National Institute for Medical Research.** Methods of recording body-temperature and pulse and respiration rates during normal work.

5. **M.R.C. Applied Psychology Research Unit.**
(a) Speed of reaction under disturbing influences such as noise or lack of sleep.
(b) Inspection skill.
(c) Tracking performance.
(d) Effects of lighting conditions on the estimation of the roughnesses of wooden surfaces.

6. **D.S.I.R. Road Research Laboratory.**
(a) Design of road signs.
(b) Factors influencing driver behaviour.
(c) Vehicle design in relation to safety.
(d) Telemetry apparatus.

7. **British Iron and Steel Research Association.** Ergonomic problems in the steel industry dealt with by the Association's Ergonomics Advisory Service.

8. **General Post Office.**
(a) Keyboard design.
(b) Coding and sorting equipment for automatic letter sorting.
(c) Anthropometric desk and seat design.

ERGONOMICS RESEARCH SOCIETY

PROCEEDINGS

A Meeting was held jointly with the British Occupational Hygiene Society at the London School of Hygiene and Tropical Medicine on 24th June, 1960.

The following papers were delivered:

(1) " The Biological Effects of Air Conditioning ", by R. Hinchcliffe, M.R.C. Wernher Research unit on Deafness.

(2) " The Diurnal Variation of Warmth and Discomfort in some Buildings in Singapore ", by C. G. Webb, D.S.I.R. Building Research Station.

The buildings of Malaya and Singapore are of a well-defined type, calculated to make the best of a typically equatorial climate—warm, humid and airless. They are unheated, cooking being done outside wherever possible; they are well shaded from the sun and sky, and oriented to minimize the solar heat load; and they are exceptionally well ventilated. The thermal capacity is low. Their function is to resist heat entry, while encouraging the outflow of metabolic heat and moisture.

The indoor climates are warm, the wet-bulb temperature rising well into the eighties Fahrenheit, in which range the wet-bulb temperature itself is known to give a good indication of subjective warmth. Its average diurnal variation in 14 buildings studied showed a peak at mean noon and another at sunset, followed by a long decline until just before sunrise.

The diurnal variations of the air temperature, relative humidity and rate of air movement were shown, and their distinctive features commented on. The globe thermometer reading was rarely found to differ from the air temperature to any significant extent.

On the subjective side, corresponding graphs were shown of the comments by 14 subjects on sweating, of their subjective assessments of warmth, and of thermal discomfort. The values of the Equatorial Comfort Index had been calculated; and the features of its diurnal variation were commented on in relation to the personal reactions of the subjects.

The data are intended to provide a conspectus of the climates in Singapore buildings in 1949–50, a period when there was considerable overcrowding, and electric fans were lacking owing to a post-war shortage. Thermal discomfort was then rife. Indoor climates in Singapore have since changed in certain respects, but it is not certain that the net change constitutes an improvement.

(3) " Some Reflections on the Summer Comfort Problem in Factories ", by J. K. Page, University of Sheffield.

(4) " The Design of Buildings near modern Airports ", by E. F. Stacey, D.S.I.R. Building Research Station.

(5) " Visual Problems involved in the Continuous Performance of Fine Work in Industry", by C. H. Bedwell, Northampton College of Advanced Technology.

A Meeting was held on 23rd September, 1960, at the Department of Psychology, Reading University.

The following papers were delivered :

(1) " Selecting a Milking Parlour for the Individual Farm ", by W. P. Roberts, British Oil and Cake Mills Ltd.

This paper described part of the research, which has been conducted at Reading University, into the problem of designing farm buildings to suit specific conditions.

The two items discussed concerned milking parlour designs and were (*a*) the choice of the optimum combination of milking-machine units and cow-stalls to suit particular herd requirements, and (*b*) a comparison of energy expenditure between single-level milking, in which cows and operator are on the same floor level, and two-level in which the operator works in a pit some 2 ft. 6 in. below the level at which the cows stand.

In theory, if a particular combination of machine units and cow-stalls is specified and the average milking time of a herd is known, it is possible to predict the ' performance ' of a milking parlour in terms of:

(i) Throughput of cows per man-hour.
(ii) Average available feeding time.
(iii) Average available working routine time.

This theory was tested in the field and was found to be both accurate and practical.

Further research was carried out in order to find the time required by cows to eat their concentrate foods, the time needed by operators to do routine work during milking, and the 'machine time' required by cows according to their yield. The final result is a formal system of choosing a parlour which ensures the optimum combination of machine units and cow-stalls according to any specific management conditions.

Energy expenditure trials showed that it requires about 50 per cent more energy to milk in a single-level installation but that, in terms of energy expenditure, milking cannot be classed as heavy work.

(2) "Human Factors limiting the Speed of a Tractor-drawn Implement", by M. Upton, Reading University.

The importance of labour and machinery costs in agriculture was illustrated by reference to a survey carried out in Southern England. Labour and machinery together accounted, on average, for almost half the gross output. There was a tendency for low profits to occur where these costs were high.

It was pointed out that productivity of labour and machinery in agriculture depends not only on the rate of working, but also on the farming system. The requirement of men and machines for a given system depends upon the maximum or peak requirement. Since the rate of working at peak requirement determines the size of the peak, it must in turn determine the labour and machinery required. It is in this way that working rates influence productivity. Peaks occur particularly with crop work and the paper was therefore concerned with rates of working of field crop machines.

Basically, rates of working are determined by the effective working width and forward speed of the machine. They are also affected by turn time, preparation and servicing time, breakdowns and rest allowances. In preparation and servicing, man may be involved as a prime mover. His performance will depend only upon the method used and his energy expenditure. There is often scope for improvement in such cases by further mechanisation and method study. Forward speed and working width, turn time and rest allowance may all be influenced by the driver as a controller.

The three main human factors which may restrict forward speed are the safety and the comfort of the driver, and his tracking ability.

The dangers of tractors overturning at high speeds were mentioned and the possibility discussed of reducing anxiety, while allowing speeds to be increased, by the use of a protective superstructure developed at the National Institute of Agricultural Engineering. Comfort is affected by the tractor vibration. Discomfort is greatest at high amplitudes and frequencies of vibration. High amplitudes occur by amplification when the tractor is vibrated at its natural frequency. Higher forward speeds can lead to higher frequencies of vibration, outside the range of the tractor's natural frequency, and thus discomfort to the driver may be less at higher speeds. Tracking ability is likely to restrict speed in row crop work where a high degree of accuracy is required. Work done at the National Institute of Agricultural Engineering and at Reading which illustrates the effect of speed on steering accuracy was discussed. Much more data are required on all these three effects and their magnitudes.

Turn times could be affected by human factors. Timings made at Reading, however, showed no difference between individuals in the time taken to make a given turn at a given approach speed.

Little information is available about what rest allowances are necessary, but it was suggested that the need is likely to occur only when the driver is under stress in dangerous or uncomfortable conditions such as steep slopes or rough ground, or when tracking very accurately.

Ergonomics in agriculture should aim not only at improving the worker's welfare, but also at allowing him to work at higher rates.

(3) "Estimation of Averages from Numerical and Graphical Data", by J. Spencer, Reading University.

A consideration of the process operator's task of controlling chemical plant led to the supposition that some ability to extract average values from fluctuating populations of readings on indicators must be acquired by the operator. These averages form part of the operator's intellectual model of the plant he controls and allow him to make decisions about when and how large to make his corrections for deviations from desired operating conditions.

Some simple experiments were performed to discover how accurately people can estimate averages when presented with information in the form of numbers typed on cards and in the form of graphs in which the ordinates of plotted points were made proportional to the numbers.

Variables investigated so far are :

(i) the number of items or points presented for judgment.
(ii) the time available for study of the presented material.
(iii) the scatter of the numbers or points about their mean.

Normal distributions of values about their mean were used for most of the material. A variant was used in which all but one value or point were normally distributed. The one item was markedly different in value from its fellows.

Subjects were university undergraduates of both sexes and process operators from a large organic chemical factory.

Results so far indicate that the reliability and accuracy of judgments is superior for material presented graphically. This superiority is much more marked for increased scatters and amount of information, the effect of scatter being the most important. The scatters used here were either ' low ' (σ in the range 1·4–4·1) or ' high ' (σ in the ranges 5·2–24·1) and amounts were either 10 or 20 items presented for judgment.

The average error of estimations based on group results is small lying in the range 0·5 to 2·75 per cent for students and in the range 1 to 6·5 per cent for process operators. The percentages quoted are obtained by dividing average error by six times the standard deviation of the data on which the estimates were made, expressed as a percentage.

Average estimates are definitely affected by ' rogue ' values, that is, by the presence of a single value which differs widely from other members of the series. The interesting feature is that, for symbolic material, judgments tend to swing in the direction of the rogue. For graphical material, judgments tend to be swung in the reverse direction. A second interesting feature is that this influence on judgment of a rogue value is more pronounced among people of moderate ability at estimating averages. People who are either good or poor at the task tend to be influenced less by a rogue.

The time allowed to study the information was 10 sec for most of the experiments. From an initial study made on undergraduates no difference attributable to amount of time available was found when low-scatter information was presented for 5 or 10 sec. Performance did deteriorate for high-scatter material seen for only 5 sec as compared to 10 sec. On the basis of these results it was decided to use 10 sec viewing time in all the later experiments.

Using graphical material, an examination was made of subjects' predictions for the position of the next value to be added to the graph. It was found that subjects were very consistent in their predictions although no absolute criterion existed on which to base judgment. Also subjects responded sensitively to trends in the graph when making predictions.

It is suggested that general intellectual ability is one of the principal determinants of averaging ability but this remains to be tested. Suggestions were made for further experiments to show more clearly what sort of mechanism seems to be operating when people average presented information.

(4) " Fixation-time, Signal Frequency, and Missed Signals in a Simple Inspection Task ", by E. R. F. W. Crossman, Reading University.

Mackworth (1950) and others have shown in the laboratory that when an operator is called on to detect wanted signals occurring at random among numerous similar unwanted ones, he tends to miss a large proportion of them, even though the difference between the wanted and unwanted signals is well above threshold. Similar findings have been reported in industrial inspection tasks by McKenzie (1958) and others. Broadbent (1958) has discussed four alternative hypotheses which might explain this phenomenon, but none of them is wholly satisfactory. The experiment was intended to test a further hypothesis based on consideration of scanning behaviour. The operator, scanning a sequence of items, will spend a certain time examining each, and it is supposed that this time depends on the *average information per item,* which falls with the frequency of wanted items. But the *information per wanted item,* and hence the response time, would correspondingly rise, and wanted signals would be missed simply because too little time was devoted to their examination.

Subjects were asked to inspect pages of typewritten ' n's ' spaced $\frac{1}{2}$ in. apart, 12 per line, 5 lines per page, and to detect and mark inverted ' u's ' scattered among them (e.g. n n u n). ' U 's were inserted in the proportions, 1: 2, 8, 32, 128, 512, giving 1, 3, 5, 7, 9 bits per ' u ', and average information 1, 0·5, 0·2, 0·7, 0·02, 0·02 bits per item. Subjects inspected 10 pages of each in random order, being told beforehand about how many ' u 's to expect in each set.

Contrary to the hypothesis being tested, the average time per item (about 0·3 sec) did *not* decrease materially with average information ; 5–25 per cent of ' u 's were missed in the 5, 7 and 9 bit tasks, the proportion tending to increase with speed. Some subjects'

eye-movements were recorded by the E.O.G. method ; fixation-times for 'n 's were found to remain remarkably steady at about 0·25 sec. On coming to a 'u', the eyes either remained fixated on it until the mark had been made, or moved on to the next item after the normal fixation-time and returned, these two patterns occurring with about equal frequency. Thus some eye-movement response to a 'u' was apparent within 0·25–0·40 sec at all frequencies. The full response-time, from first fixating a 'u' to beginning to mark it, ranged from about 0·7 sec for 1 bit to 1·1 sec for 9 bits per 'u', this increase being very much smaller than would be predicted from a simple application of information theory.

Most of the 'u 's missed were not fixated, subjects being inclined to skip items at the ends of lines and pages. Some were fixated for times shorter than average (e.g. 0·15 sec) ; a very few were fixated for the normal time (0·2–0·3 sec) without a response being made. Thus at least two types of omission could be distinguished, due to faulty eye-movement pattern and due to failure of response to a normally fixated signal.

Since the predicted increase in scanning speed did not take place in this task, a modified version with a dot inside each 'u' enabling subjects to detect them in peripheral vision, was tried. Preliminary trials showed a completely different pattern of scanning, and a marked decrease in fixations per page with frequency of wanted signals. It seemed possible that the original hypothesis might fit this case.

References

Broadbent, D. E., 1958. Perception and Communication. (London : Pergamon Press).

McKenzie, R. M., 1958. On the accuracy of inspectors. *Ergonomics*, **1**, 258–72.

Mackworth, N. H., 1950, Researches on the measurement of human performance. *Medical Research Council Special Report No.* 268. (London : H.M.S.O.)

(5) "Eye Movements in a Simple Searching Task", by B. Shackel, Psychological Research Laboratory, E.M.I. Electronics, Feltham, Middlesex.

Although there have been many studies of other aspects of eye movements in vision and perception, relatively little attention has been given to the process of searching for inconspicuous objects. Visual search consists of a series of eye-movements, each of which takes the eyes to a different fixation point to enable inspection of a different part of the search area.

Based on a pioneer study of Oldfield (1947), experiments have been done to examine the influence upon eye movement and task performance of variations in the brightness and size of the inconspicuous object and in the size of the search field. The eye-movement recording technique used has been reported elsewhere (Shackel 1960). Since the experiments were done, two important studies of searching have been reported, by Enoch (1959) and Ford *et al.* (1959), upon different variables and types of task.

The general trends in performance, under the conditions studied, were as follows. The eyes actually passed over the object, without seeing it on the first possible occasion, on an average of 20 per cent of the trials. The detection time, the percentage of trials in which the object was overlooked, and the number of movements and regressions per line, decreased as the brightness and size of the object were increased. The average length of eye-movement between each fixation increased as the brightness and size of the object were increased; again the length of inter-fixation movements, and also the number of movements and of regressions per line, increased as the size of the search field was increased. Each subject showed a general constancy in his eye-movement pattern, and also in the percentage of time he searched in different parts of the field, under the various conditions of object and search field. There were, however, large differences between subjects in their average detection time and inter-fixation movements. These results were reported in detail and compared with the findings of other workers. Some of their implications were discussed.

References

Enoch, J. M., 1959, Effect of the size of a complex display upon visual search. *J. opt. Soc. Amer.*, **49**, 280–286.

Ford, A., White, C. T., and Lichtenstein, N., 1959, Analysis of eye movements during free search. *J. opt. Soc. Amer.*, **49**, 287–292.

Oldfield, R. C., 1947, Visual search for an inconspicuous object. Flying Personnel Research Committee Report No. 681.

Shackel, B., 1960, Pilot Study in Electro-Oculography. *Brit. J. Ophthal.*, **44**, 89–113.

ANNUAL CONFERENCE, 1961 : April 17th–20th

UNIVERSITY OF BRISTOL

PROVISIONAL PROGRAMME

Monday, April 17th, p.m., SYMPOSIUM ON CLIMATIC CONDITIONS

The Energy Cost of Coal-mining and its Bearing on Tolerance Limits, by P. Humphries, M.R.C. Unit for Research on Climate and Working Efficiency, Oxford.

Heat Stress in a Glass Factory, by J. W. Snellen, Netherlands Institute for Preventive Medicine, Leyden, Netherlands.

Ventilation and the Thermal Environment, by H. R. Lambie, Colt Ventilation Ltd., Surbiton, Surrey.

Field Experiments on the Effects of Stress in a Hot Climate, by O. G. Edholm, National Institute for Medical Research, Hampstead.

Work in low Temperatures, by Dr. Wesseling, Amsterdam, Netherlands.

5.30 p.m., CONFERENCE ADDRESS by Dr. T. Bedford

Tuesday, April 18th, a.m.

The Physiological Effect of Whole-Body Vibration, by J. Ernsting, R.A.F. Institute of Aviation Medicine, Farnborough.

Studies of Brightness Discrimination as a Basis for Eye-Movements Research, by N. S. Kirk, Division of the Senior Psychologist, Manpower Department, Admiralty.

Operational Validity in Military Field Trials, by N. H. Hayes, Army Operational Research Group, West Byfleet.

Two other papers based on research in military ergonomics will be arranged for this session.

p.m., SYMPOSIUM ON FITNESS AND TRAINING

Towards a General Theory on Human Performance, by L. E. Morehouse, Department of Physical Education, University of California.

Training and Personality as Determinants of Exercise Hyperventilation, by K. Kemp, Chemical Defence Experimental Establishment, Porton.

One or more further papers will be included in this Symposium. A Symposium on Ageing or on research into complex skills may be arranged in parellel with this session.

Wednesday, April 19th, a.m.

Functional Anthropometry, by R. J. Whitney, M.R.C. Laboratories, Hampstead.

Manual Lifting of Loads, by P. A. van Wely, N.V. Philips' Gloeilampenfabrieken, Eindhoven, Netherlands.

Lighting and Industrial Stress, by H. C. Weston, Formerly of the Institute of Ophthalmology, London.

Blood Alcohol Level and Work Accidents, by B. G. Metz, University of Strasbourg, France.

Safety Harness in Cars, by H. C. W. Stockbridge and J. Dennis, Clothing and Stores Experimental Establishment, Farnborough.

p.m.

Reactions of Pulse Rate and Blood Pressure in Dynamic and Static Work, by G. C. E. Burger, N.V. Philips' Gloeilampenfabrieken, Eindhoven, Netherlands.

The Physiological Aspects of Shift Work, by F. H. Bonjer, Netherlands Institute for Preventive Medicine, Leyden.

Influence of Shift Work, by G. Wesseldijk, N.V. Philips' Gloeilampenfabrieken, Eindhoven, Netherlands.

Ergonomic Problems in Management Consultancy, by C. B. Jackson, Urwick Orr and Partners Ltd., London.

The Designer's Demands upon the Ergonomist, by W. H. Mayall, Council of Industrial Design, London.

Arrangements will be made to hold informal discussions, preferably on Wednesday evening.

Thursday, April 20th

The Conference will end after Breakfast today.

Registration forms may be obtained from

Dr. S. Griew,
University of Bristol,
Department of Psychology,
22 Berkeley Square, Bristol 8.

THE ERGONOMICS RESEARCH SOCIETY

LIST OF MEMBERS AND THEIR APPOINTMENTS—1961

Addresses are in Great Britain unless otherwise specified
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BANISTER, H., B.Sc., M.Sc., Ph.D., Taylor & Francis Ltd., London.
BARBOUR, A. Buchanan, O.B.E., O.St.J., M.R.C.S., L.R.C.P., F.R.Ae.S., Director of Medical Services, British European Airways, Hounslow, Middlesex; Medical Adviser Cyprus Airways, Gibraltar Airways and Alitalia, Medical Consultant to Aer Lingus.
BARCROFT, H., M.A., M.D., M.R.C.P., F.R.S., Professor of Physiology, St. Thomas's Hospital Medical School, University of London.
BARKLA, D. M., B.Sc., Research Officer, Furniture Development Council, London.
BARLOW, W., B.A., B.M., B.Ch., Physician, Dept. of Physical Medicine, Wembley Hospital, London.
BASTEINER, Herve A. L., M.D., Chargé de Cours, Laboratoire d'Hygiène, University of Brussels, Belgium.
BEGBIE, G. H., M.A., Ph.D., M.B., Ch.B., Lecturer in Physiology, University of Edinburgh.
BELBIN, R. M., M.A., Ph.D., Management Consultant, Cambridge.
BELDING, H. S., M.A., Ph.D., Professor of Environmental Physiology, Dept. of Occupational Health, University of Pittsburgh, Pa, U.S.A.
BENNETT, M. G., M.Sc., F.Inst.P., F.Inst.F., Superintendent, Operational Research Division, Research Dept., British Railways, London.
BERGIN, K. G., O.St.J., M.A., M.D., D.P.H., F.R.Ae.S., Director of Personnel and Medical Services, B.O.A.C., London Airport, Master of the Guild of Air Pilots and Air Navigators, Medical Advisor to the Air League of the British Empire.
BINK, B., M.D., Physiologist, Dept. of Occupational Medicine, Netherlands Institute for Preventive Medicine, Leyden, Holland.
BODY, R. B., M.R.C.S., L.R.C.P., D.I.H., Resident Doctor, Steel Company of Wales Ltd., Abbey, Margam and Port Talbot Works, S. Wales.
BONJER, F. H., M.D., Chief of Dept. of Occupational Medicine, Netherlands Institute for Preventive Medicine, Leyden, Holland.
BORGER, R., B.Sc., M.A., Lecturer, Dept. of Management and Production Engineering, Brunel College of Technology, London.
BOUMAN, M. A., Ph.D., Director, Institute for Perception, R.V.O.–T.N.O., National Council for Applied Research, Soesterburg, Holland.
BOWEN, H. M., Ph.D., Senior Psychologist, Dunlap and Associates Inc., Stamford, Conn., U.S.A.
BOX, A. W., B.A., Scientific Officer, Operational Research Dept., B.I.S.R.A., London.
* BROADBENT, D. E., M.A., Director, M.R.C. Applied Psychology Research Unit, Cambridge.
BROOKS, C. E., B.Sc., Training Manager, Personnel Administration Ltd., London.
BROUGH, B. M., B.Sc., Head of the Organization and Methods Branch, British European Airways, Ruislip, Middlesex.
BROWN, I. D., Graduate I.E.E., Scientific Officer, M.R.C. Applied Psychology Unit, Cambridge.
BROWN, J. R., M.B., B.S., B.Sc., Professor, Dept. of Physiological Hygiene, University of Toronto, Canada.
* BROWNE, R. C., M.A., D.M., M.R.C.P., Nuffield Professor of Industrial Health, University of Durham, King's College, Newcastle-upon-Tyne.
BROZEK, J., Ph.D., Professor and Chairman, Dept. of Psychology, Lehigh University, Bethlehem, Pa., U.S.A.
BRUUSGAARD, A., M.D., Senior Medical Inspector of Factories, Oslo, Norway.
* BURNS, W., D.Sc., M.D., Ch.B., Professor of Physiology, Charing Cross Hospital Medical School, London.
BURRY, H. S., B.Sc., M.A., Physiologist, British Boot, Shoe & Allied Trades Research Association, Kettering.

CAVANAGH, P., M.A., Dip. Psych., Lecturer, Dept. of Psychology, Birkbeck College, University of London.
CHAMPNESS, J. H., Ph.D., Psychologist, Dept. of Education, Hobart, Tasmania, Australia.
CHATTERJEE, S. K., M.B., B.S., Ph.D., D.P.H., D.I.H., Medical Inspector of Factories, Bihar, Patra, India.
CHENNELLS, Miss Mary H. D., B.Sc., Ph.D., Lecturer, Physiology Dept., University of Melbourne, Victoria, Australia.
CHRENKO, F. A., B.Sc., A.M.I.H.V.E., M.R.C. Laboratories, Holly Hill, Hampstead, London.
CLAY, Miss H. M., M.A., Senior Scientific Officer, Dept. of Scientific and Industrial Research, London.
CLEAVER, E., Body Experimental Engineer, Austin Motor Co., Ltd., Birmingham.
* CLEMENTS, E. M. B., M.B., B.S., Medical Research Council, London.
CLUSELLAS, G., Industrial Designer, Buenos Aires, Argentina.

Collin, D. A., M.A., Lecturer in Industrial Psychology, Regent Street Polytechnic, London.
Colquhoun, W. P., M.A., Ph.D., Scientific Officer, Applied Psychology Research Unit, Cambridge.
Connolly, J. V., B.E., F.R.Ae.S., M.I.Prod.E., Director, Sunbridge Park Management Centre, Bromley, Kent.
* Conrad, R., M.A., Ph.D., Assistant Director, M.R.C. Applied Psychology Research Unit, Cambridge.
Cook, S. L., B.Sc., Manager, Operational Research Dept., Richard Thomas & Baldwins Ltd., Ebbw Vale, Mon.
Cooke, H. M., M.Sc., Head of Human Operational Research Division, Applied Physiology Laboratory, Transvaal and Orange Free State Chamber of Mines, Johannesburg, South Africa.
Cotes, J. E., M.A., B.M., B.Ch., M.R.C.P., Applied Physiologist, M.R.C. Pneumoconiosis Research Unit, Penarth, Glam.
De Coulon, P., Ph.D., Head of Psychological Dept., Ebauches Ltd., Neuchatel, Switzerland.
Courtney-Coffey, G. A., Managing Director, Taylor & Francis Ltd., London.
Cox, David, B.A., Chief Work Study Engineer, Richard Thomas & Baldwins Ltd., Redbourn Works, Scunthorpe, Lincs.
Crockford, G. W., B.Sc., Physiologist, M.R.C. Unit for Research on Climate and Working Efficiency, Dept. of Human Anatomy, University of Oxford.
Crossman, E. R. F. W., M.A., Ph.D., Lecturer in Psychology, University of Reading.
Crowden, G. P., O.B.E., T.D., D.Sc., M.R.C.P., M.R.C.S., Professor of Physiology and Director of Dept. of Applied Physiology, London School of Hygiene and Tropical Medicine, University of London.

* Darcus, H. D., M.A., B.M., B.Sc., Research Officer, R.A.F. Medical Rehabilitation Unit, Chessington, Surrey.
Davies, L. G., Technical Director, Colt Ventilation Ltd., Surbiton, Surrey.
Davis, L. E., M.S., Associate Professor of Industrial Engineering, University of California, Berkeley, U.S.A.
Daynes, F. K., Methods Engineer, W. H. Allen, Sons & Co., Bedford.
De Jong, J. R., Dr.Tech.Sc., Management Consultant, Hengelo, Holland.
Dennis, J. P., B.A., Senior Psychologist, C.E.P.R.E., Farnborough, Hants.
Dilke, N. W., Senior Lecturer in Work Study, Seale-Hayne Agricultural College, Newton Abbot, Devon.
Dodds, S., Bachelor of Industrial Design, Technical Officer, Human Factors Wing, Defence Research Medical Laboratories, Toronto. Canada.
Dudley, N. A., B.Sc., Ph.D., M.I.Prod.E., Professor of Engineering Production, Head of Dept. and Director of Institute for Engineering Production, University of Birmingham.
Durnin, J. V. G. A., M.A., M.B., Ch.B., Lecturer, Institute of Physiology, University of Glasgow.
Dyce-Sharpe, Miss K., B.Sc., Lecturer, Loughborough College of Technology, Loughborough, Leics.

Eckenrode, R. T., B.Chem.Eng., Senior Research Associate, Dunlap & Associates, Inc., Stamford, Conn., U.S.A.
* Edholm, O. G., M.B., B.S., M.R.C.S., L.R.C.P., Head of the Division of Human Physiology, M.R.C. Laboratories, London, N.W. 3.
Edwards, E., B.A., Lecturer in Ergonomics, Dept. of Ergonomics and Cybernetics, Loughborough College of Technology, Loughborough, Leics.
Eklof, Gunnar, Dept. of Furniture and Interior Design, Konstfackskolan, Stockholm, Sweden.
Ellis, Surg-Cmdr. W. H. B., R.N., A.F.C., M.D., B.S., Farnham, Surrey.
Ely, J. H., Ph.D., Assistant Vice-President and Program Director, Dunlap & Associates Inc., Stamford, Conn., U.S.A.
Entwisle, D. G., B.Sc., Psychologist, Philips Electrical Ltd., London.

Fitts, Paul M., A.M., Ph.D., Professor of Psychology and Director of the Aviation Psychology Laboratory, Ohio State University, Columbus, Ohio, U.S.A.
Fletcher, E., M.A., A.S.A.A., Production Dept., T.U.C., London.
Fletcher, John G., M.Sc., Ph.D., F.R.I.C., Defence Research Medical Laboratories, Toronto, Canada.
* Floyd, W. F., B.Sc., Ph.D., F.Inst.P., A.M.I.E.E., Head of Dept. of Ergonomics and Cybernetics, Loughborough College of Technology, Loughborough, Leics.
Ford, A. B., M.D., Instructor in Medicine, Western Reserve University, Cleveland, Ohio, U.S.A.
Forssman, S. P. M., M.D., Medical Adviser to the Swedish Employers' Confederation; Associate Professor of Occupational Health, Stockholm, Sweden.
Fortuin, G. J., M.D., Deputy Director, Medical Service, Philips' Factories, Eindhoven, Holland.
Frisby, C. B., Ph.D., B.Comm., Director, National Institute of Industrial Psychology, London.

Galloway, G. F., B.Sc., Wh.Sch., Ph.D., M.I.Mech.E., M.I.Prod.E., A.M.I.E.E., M.Inst.Pet., Director of Research, Production Engineering Research Association, Melton Mowbray, Leics.

Gerhard, D. J. J., M.A., Ph.D., Senior Scientific Officer, Dept. of Scientific and Industrial Research, London.
Glover, J. R., M.A., M.B., B.Chir., D.I.H., Industrial Medical Officer, Westinghouse Brake & Signal Co. Ltd., Chippenham, Wilts.
Goldberg, L., M.D., Associate Professor of Pharmacology, Karolinska Institute, Stockholm, Sweden.
Golds, L. B. S., M.I.E.E., F.R.S.A., Chief Engineer, Eastern Electricity Board, Ipswich.
Grandjean, E., M.D., Professor of Physiology and Director of the Institute fuer Hygiene und Arbeitsphysiologie der Eidgenoessischen Technischen Hochschule, Zurich, Switzerland.
Graves, R. F., Senior Management Consultant, John Evans & Co., Birmingham.
Green, L. V., Manager, Work Study Dept., Dunlop Rubber Co. Ltd., Erdington, Birmingham.
Grieve, Mrs. J. I., B.Sc., Scientific Officer, Physiological Unit, Post Office Research Station, Dollis Hill, London.
Griew, S., B.Sc., Dip.Psych., Ph.D., Lecturer in Psychology, University of Bristol.

Haerdi, R. J., Work Study Engineer, British Boot, Shoe & Allied Trades Research Association, Kettering.
Harcourt, R. A. F., M.A., Head of Dept. of Management and Production Engineering, Brunel College of Technology, London.
Harper, R., M.Sc., Ph.D., Lecturer in Industrial Psychology, University of Leeds.
Harper, W. R., Research Engineer, Canadain National Railways, Montreal, Canada.
Hatch, T. F., B.S., S.M., Professor of Industrial Health, University of Pittsburgh; Research Adviser, Industrial Hygiene Foundation, Mellon Institute, Pittsburgh, Pa., U.S.A.
Hayes, N. H., B.Sc., Army Operational Research Group, West Byfleet, Surrey.
Hellon, R. F., B.Sc., D.Phil., Physiologist, M.R.C. Unit for Research on Climate and Working Efficiency, Dept. of Human Anatomy, University of Oxford.
Henderson, P., M.A., Psychologist, C.E.P.R.E., Farnborough, Hants.
* Hick, W. E., M.A., M.D., F.B.Ps.S., Reader in Experimental Psychology, University of Cambridge.
Hill, F., Director of Recruitment, Education and Training, The Wool (and Allied) Textile Employers' Council, Bradford, Yorks.
Holding, D. H., M.A., Lecturer in Psychology, University of Leeds.
Holmquist, Carl-Eric R., Chem.Eng., M.Sc., The Swedish State Power Board, Stockholm, Sweden.
Hopkinson, R. G., B.Sc., Ph.D., M.I.E.E., F.I.E.S., F.R.P.S., Senior Principal Scientific Officer, D.S.I.R., Building Research Station, Garston, Watford, Herts.
Howse, H. D., M.B.E., D.S.C., Human Factors Section, Atomic Energy Division, General Electric Co. Ltd., Erith, Kent.
Humphrey, P. B., B.A., Psychologist, Army Operational Research Group, Byfleet, Surrey.
Humphreys, P. W., B.Sc., N.C.B. Research Physiologist, Unit for Research on Climate and Working Efficiency, Dept. of Human Anatomy, University of Oxford.

Iannaccone, A., M.D., Asst. Professor of Internal Medicine and Asst. Director of Institute for Occupational Medicine, University of Florence, Italy.

Jackson, C. V., M.A., B.Sc., Management Consultant, Urwick Orr & Partners, London.
James, D. John, M.A., Psychologist, Research Branch, H.Q., Flying Training Command, R.A.F., Shinfield Park, Reading, Berks.
Jeffery, J. A., D.L.C., Lecturer in Physical Education, Loughborough College of Technology, Loughborough, Leics.
Johnston, D. L., B.Sc., A.M.I.E.E., M.S.I.A., Urwick Orr & Partners, London.
Jones, A. H., B.A., M.B., B.Ch., Divisional Medical Officer, British Railways (Southern Region), London Bridge Station, London.
Jones, J. Chris., B.A., Industrial Design Ergonomics Laboratory, Metropolitan-Vickers Electrical Co. Ltd., Manchester.

Kane, J. E., Dip.Phys.Ed., Senior Lecturer, Dept. of Physical Education, St. Mary's College, Twickenham.
Karvonen, M. J., Ph.D., M.D., Director of the Physiological Dept., Institute of Occupational Health, Helsinki, Finland.
Kerslake, D.McK., M.B., B.S., Ph.D., Physiologist, R.A.F. Institute of Aviation Medicine, Farnborough, Hants.
King, S. D. M., M.A., Managing Director, Organization and Training (Consultants) Ltd., London.
Koene, G. B. M. L., Lic.Psy.App., Staff Psychologist, Staatsmijn Maurits, Geleen, Holland.
Kothari, D. S., Scientific Advisor to the Ministry of Defence, Government of India, and Honorary Professor of Physics, University of Delhi, India.
Kozlowski, W. K., Advisor to the Minister of Industry and Handicrafts, Warsaw, Poland.
Krendel, E. S., B.A., Sc.M., M.A., Head of Engineering Psychology Branch, Franklin Institute, Philadelphia, U.S.A.
Kurke, M. I., B.A., M.A., Dunlap & Associates Inc., Washington, D.C., U.S.A.

LACEY, R. G., B.Sc., Dept. of Ergonomics, College of Aeronautics, Cranfield.
LADELL, W. S. S., B.A., M.B., B.Ch.. M.R.C.S., L.R.C.P., Superintendent, Medical Division, C.D.E.E., Porton, Wilts.
LAL, Harbans, B.Sc., Major, Indian Army, Inspectorate of General Stores, New Delhi, India.
LANE, J. C., M.B., B.S., Director of Aviation Medicine, Dept. of Civil Aviation, Victoria, Australia.
LANER, S., B.A., Ph.D., Operational Research Dept., B.I.S.R.A., London.
LAURIE, W. D., M.A., A.M.I.E.E., Naval Motion Study Unit, Teddington.
LECOULTRE, Mlle. D., M.A., European Productivity Agency, Paris, France.
LEHMANN, G. C., M.D., Professor of Physiology and Director of the Max-Planck-Institut fuer Arbeitsphysiologie, Dortmund, Germany.
LEITHEAD, C. S., M.B., Ch.B., D.T.M. & H., D.Obst., Lecturer in Tropical Medicine, University of Liverpool.
LEWIS, H. E., B.Sc., M.B., Ch.B., Division of Human Physiology, M.R.C. Laboratories, London.
LIND, A. R., B.Sc., D.Phil., Research Physiologist, N.C.B., Dept. of Human Anatomy, University of Oxford.
LIPPERT, S., B.A., Coordinator of Human Factors Group, Douglas Aircraft Co. Inc., Santa Monica, Ca., U.S.A.
LONG, M. C. W., M.B., B.S., M.R.C.S., L.R.C.P., Chief Medical Officer, G.P.O., London.
LOCKWOOD, A. H. R., Senior Work Study Officer, Army Work Study Group, Byfleet, Surrey.
LONGTON, P. A., M.A., Asst. Operational Research Officer, British European Airways, Ruislip, Middx.
LOVELESS, N. E., M.A., Ph.D., Lecturer in Psychology, Queen's College, Dundee.
LUNDERVOLD, A., M.D., Neurological University Clinic, Oslo, Norway.
LUNDGREN, N. P. V., M.D., Director, Division of Industrial Physiology, G.C.I., Stockholm, Sweden.

MCFARLAND, Ross A., B.A., Ph.D., Hon.Sc.D., Associate Professor of Industrial Hygiene, Harvard School of Public Health, Boston, Mass., U.S.A.
MCGIRR, P. O. M., M.D., Ch.B., D.P.H., D.I.H., Medical Officer, B.O.A.C., London.
MACKWORTH, N. H., M.B., Ch.B., Ph.D., Dunlap and Associates Inc., Stamford, Conn., U.S.A.
MACMILLAN, J. W., B.A., Ph.D., Director of Personnel-Development, Canada Packers Ltd., Toronto, Canada.
MAULE, H. G., M.A., Ph.D., Senior Lecturer in Occupational Psychology, London School of Hygiene and Tropical Medicine, University of London.
MEAD, Leonard C., A.B., A.M., Ph.D., Tufts University, Medford, Mass., U.S.A.
MELDRUM, T., A.M.I.Mech.E., A.M.I.Prod.E., Lecturer in Work Study, Watford Technical College.
METZ., B. G., B.Sc., M.D., Associate Professor of Physiology, University of Strasbourg, France.
MIGLIORINO, Prof. G., Dott.Med., Chief Inspector, Medical Service, Italian Railways, Director of Applied Psychology Laboratory, University of Palermo, Sicily, Italy.
MOLLOY, C. C., M.B., B.S., B.Sc., A.R.I.C., D.I.H., Factory Medical Officer, War Dept. Medical Service, Chorley, Lancs.
MOORE, R. L., B.Sc., M.Sc., (Tech.) A.Inst.P., Senior Principal Scientific Officer, Road Research Laboratory, Harmondsworth, Middx.
MORANT, G. M., D.Sc., Bishop's Waltham, Hants.
MOREHOUSE, L. E., B.S., M.Ed., Ph.D., Professor of Physical Education, University of California, Los Angeles, U.S.A.
MORGAN, Clifford T., A.B., M.A., Ph.D., Dept. of Psychology, University of Wisconsin, U.S.A.
MURRELL, K. F. H., M.A., F.R.P.S., Research Fellow in Psychology, Head of the Unit for Research on Employment of Older Workers, University of Bristol.
MOUND, S. H., Head of the Motion Study Wing, Army Operational Research Group, Byfleet, Surrey.
MÜLLER, E. A., M.D., Professor of Physiology, University of Munster and Head of Physiological Dept., Max-Planck-Institut fuer Arbeitsphysiologie, Dortmund, Germany.
MURCH, S. J., Naval Motion Study Unit, Teddington.

NAILON, P. W., B.Sc., Dept. of Hotel and Catering Management, Battersea College of Technology, London.
NEWBY, R. W., B.Sc., A.M.I.E.E., A.C.G.I., D.I.C., H.M. Inspector of Factories, Wolverhampton.
NEWNHAM, C. T., M.R.C.S., L.R.C.P., Chief Medical Officer, Western Region, British Railways.
NORMAN, L. G., M.D., B.Sc., M.R.C.P., D.P.H., Chief Medical Officer, London Transport Executive, London.

OLDFIELD, R. C., M.A., Professor of Psychology, University of Oxford.
ORLANSKY, J., B.S.S., M.A., Ph.D., Vice-President, Dunlap & Associates, Inc., Stamford, Conn., U.S.A.
O'DOHERTY, Rev. E. F., M.A., Ph.D., Professor of Psychology, University of Dublin.

PACAUD, Mme. S., Docteur en Philosophie, Maitre de Récherches, Centre National de la Recherche Scientifique, Directeur-Adjoint à l'Ecole des Hautes Etudes, Chargé de Seminaire à l'Institut de Psychologie de l'Université de Paris, France.
PAGE, J. K., B.A., Professor of Building Science, University of Sheffield.
PAINTAL, A. S., M.B., B.S., M.D., Ph.D., Physiology Dept., College of Medicine, University of Utah, Salt Lake City, Utah, U.S.A.
PENTON, J. C., B.A., B.M., B.Ch., D.P.M., Senior Principal Psychologist, Army Operational Research Group, Byfleet, Surrey.
PEPLER, R. D., Ph.D., Dunlap & Associates Inc., Stamford, Conn., U.S.A.
PETERS, Miss A. D. K., O.B.E., B.A., B.M., B.Ch., Principal Medical Officer, R.O.F. War Department, London.
PLEWES, Miss D. W., Ed.D., F.A.C.S.M., Dept. of National Health and Welfare, Ottawa, Canada.
POWELL, M., B.Sc., Dip.Psych., Medical Services, N.C.B., Manchester.
PRITCHARD, J. C., M.A., Director, The Furniture Development Council, London.
PROVINS, K. A., M.A., Ph.D., M.R.C., Unit for Research on Climate and Working Efficiency, Dept. of Human Anatomy, University of Oxford.

RAPPAPORT, M., M.A., B.S., Ph.D., Associate Research Psychologist, Stanford Research Institute, Menlo Park, U.S.A.
REDMILL, J. D., M.B., B.S., Medical Officer, War Dept., London.
REID, Major A. M., B.Sc., Deputy Superintendent, C.E.P.R.E., Royal Aircraft Establishment, Farnborough, Hants.
REITMAA, B., M.Sc., General Direction of Posts and Telegraph, Division of Organization, Helsinki, Finland.
* RENBOURN, E. T., M.D., B.Sc., M.R.C.P., Superintendent, C.E.P.R.E., Royal Aircraft Establishment. Farnborough, Hants.
RIVIERE, W. D. de la, A.I.I.A., Defense Research Medical Laboratory, Toronto, Canada.
ROBSON, H. E., M.B., B.S., M.R.C.S., L.R.C.P., Principal Lecturer in Anatomy and Physiology, Loughborough Training College, Loughborough.
RODAHL, K., M.D., Dr.Med., Director of Research, Lankenau Hospital, Philadelphia, U.S.A.
RODGER, A., M.A., F.B.Ps.S., Reader in Psychology, Birkbeck College, University of London.
ROSENBAUM, S., M.A., Principal Scientific Officer, War Office, London.
ROSS, S., B.Sc., A.M., Ph.D., American Psychological Assn., Washington, D.C., U.S.A.
* RUFFELL-SMITH, G/Capt., H. P., R.A.F., Central Medical Establishment, London.

SAMUEL, J. A., B.Sc., Fleet Work Study, Admiralty, London.
SANDERS, A. F., M.Sc., Institute for Perception, R.V.O.–T.N.O., National Council for Applied Research, Soesterburg, Holland.
SCHOEFFEL, F., Dpl.Ing., Consulting Engineer, Vienna, Austria.
SCHWAB, R. S., A.B., M.A. (Cantab.), M.D., Assistant Professor in Clinical Neurology, Harvard Medical School, Boston, Mass., U.S.A.
SEARLE, L. V., Ph.D., U.S. Naval Air Missile Test Centre, Point Mogu, Calif., U.S.A.
SELL, R. G., B.Sc., Dip.Psych., Operational Research Dept., British Iron & Steel Research Association, London.
SEYMOUR, W. D., B.A., Hackmans Gate, Clent. Worcs.
SHACKEL, B., M.A., Research Psychologist, E.M.I. Electronics Ltd., Feltham, Middx.
SHAW, Miss A. G., M.A., M.I.Prod.E., Director, Anne Shaw Organization Ltd., Cheadle, Cheshire.
SILVER, P. H. S., M.B., B.S., M.R.C.S., L.R.C.P., Senior Demonstrator, Dept. of Anatomy, Middlesex Hospital Medical School, London.
SINGLETON, W. T., M.A., Lecturer in Ergonomics, College of Aeronautics, Cranfield.
SLADE, Miss I. M., M.B.E., M.Sc., Senior Research Information Officer, Central Electricity Generating Board, London.
SLATER, L., B.A., M.A., Research Associate, Dunlap & Associates Inc., Stamford, Conn., U.S.A.
SMALL, A. M., Ph.D., Manager Reliability & Quality Assurance Laboratory, Hughes Aircraft Co., Fullerton, Calif., U.S.A.
SMITH, F. E. E., M.B.E., M.R.C. Royal Naval Personnel Research Committee, Admiralty, London.
SPEAR, P., B.Eng., Director of Research, Rubury, Owen & Co. Ltd., Darlaston, Staffs.
SPENCER, J., M.A., Dept. of Psychology, University of Reading.
SPRAGG, S. D. S., B.A., M.S., Ph.D., Professor of Psychology, University of Rochester, Rochester, U.S.A.
* STANSFIELD, R. G., M.A., B.Sc., Principal Scientific Officer, Dept. of Scientific and Industrial Research, Stevenage, Herts.
STOCKBRIDGE, H. C. W., M.A., Senior Psychologist, C.E.P.R.E., Royal Aircraft Establishment, Farnborough, Hants.
STONE, W. T., Senior Experimental Officer, Directorate of Electronics Research and Development (Air), Ministry of Aviation, London.
STRINGER, J., M.A., Head, Operational Research Section, Central Electricity Authority, London.
SUFFIELD, W. H., L.R.C.P., L.R.C.S., L.D.S.R.C.S., D.P.H., D.I.H., Medical Officer, R.O.F., Bishopton, Renfrewshire.
SZAFRAN, J., M.A., Ph.D., Lecturer in Psychology, University of the South West, Exeter.

* Taylor, H. J., B.Sc., Ph.D., Superintendent, R.N. Physiological Laboratory, Alverstoke, Gosport, Hants.

Taylor, Miss V. M., B.Sc., Physiologist, British European Airways Medical Service, London Airport, Hounslow, Middx.

Thomson, M. L., M.B., Ch.B., B.Sc., Ph.D., Dept. of Applied Physiology, London School of Hygiene and Tropical Medicine, University of London.

* Tideswell, F. V., O.B.E., Ph.D., F.R.I.C., M.I.Min.E., Senior Principal Scientific Officer, Safety in Mines Research Establishment, Ministry of Fuel and Power, Sheffield.

Tucker, W. A., General Manager, T. & M. Bairstow Ltd., Keighley, Yorks.

Vandenburg, J. D., M.A., Human Factors Specialist, Grumman Aircraft Engineering Corp., Bethpage, N.Y., U.S.A.

Verhagen, C. J. D. M., Dr.ir., Lecturer in Instrumentation, Dept. of Technical Physics, Technical University, Delft, Holland.

Wallace, Miss J. G., B.Comm., Cambridge.

Wallis, D., B.Sc., Manpower Dept., Senior Psychologist's Division, Admiralty, London.

Webb, D., M.S.I.A., Salop County Council Architect's Dept., Shrewsbury.

Weddell, A. G. M., M.A., M.D., D.Sc., Reader in Human Anatomy, Dept. of Human Anatomy, University of Oxford.

* Weiner, J. S., M.A., M.Sc., Ph.D., M.R.C.S., Reader in Physical Anthropology, University of Oxford; Hon. Assistant Director M.R.C. Unit for Research on Climate and Working Efficiency, Dept. of Human Anatomy, University of Oxford.

* Welford, A. T., M.A., Lecturer in Experimental Psychology, University of Cambridge; Fellow of St. John's College, Cambridge.

Welford, N. T., M.A., M.B., B.Ch., Fels Institute, Antioch College, Yellow Springs, Ohio, U.S.A.

Whitaker, R. R., B.Mech.E., Motion Economy and Works Measurement Section, Office Administration Dept., Imperial Chemical Industries Ltd., London.

* Whitney, R. J., B.Sc., Ph.D., Head of Division of Human Biomechanics, M.R.C. Laboratories, London.

Williams, J. A. C., M.Sc., A.M.I.Mech.E., A.F.R.Ae.S., Principal, College of Aeronautical and Automobile Engineering, London.

Wilson, N. A. B., B.Sc., Ph.D., Manpower Dept., Senior Psychologist's Division, Admiralty, London.

Wisner, A. Y., Dr. M., D.Sc., Head of Physiological Section, Dept. of Scientific Research, Régie Nationale des Usines, Renault, Billancourt, France.

Wright, H. B., M.B., B.S., F.R.C.S., Medical Research Unit, Institute of Directors, London.

Wyndham, C. H., M.B., M.R.C.P., Director of the Applied Physiology Laboratory, Transvaal Chamber of Mines Research Laboratories, Johannesburg, S. Africa.

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